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Centrifuge Facility Conceptual System Study

Volume II: Facility Systems and Study Summary

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Centrifuge Facility Conceptual System Study

Volume II: Facility Systems and Study Summary

Edited by Robert Synnestvedt, Ames Research Center, Moffett Field, California

March 1991



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Space Administration

Ames Research Center
Moffett Field, California 94035-1000

PREFACE

This report presents the results of the Centrifuge Facility Conceptual System Study conducted from mid 1987 through mid 1989. The main body of the report consists primarily of charts presented at the study review held at NASA Ames Research Center (ARC) on August 17 and 18, 1989. The charts have been revised to reflect the results of that review. Explanations for the charts are provided on the adjacent pages.

The Centrifuge Facility (Facility) is the major element of the biological research facility for the implementation of NASA's Life Science Research Program on Space Station Freedom using nonhuman specimens (small primates, rodents, plants, insects, cell tissues, etc.). The Facility consists of a variable gravity Centrifuge to provide artificial gravity up to 2 earth g's, a Holding System to maintain specimens at microgravity levels, a Glovebox, and a Service Unit for servicing specimen chambers.

The initial study focused on a Centrifuge Facility for the Space Station Freedom (Freedom) U.S. Laboratory Module. Subsequently, in response to a programmatic decision to move the Centrifuge out of the U.S. Laboratory, a study was conducted to define a concept for a Centrifuge to be located in the end cone of a Node or separate module. The results of that study, although not part of the August 1989 review, are included in this report for completeness. The work reported herein is based on the Freedom configuration and capabilities prior to the program changes which occurred in late 1989. No attempt has been made to reflect the impact of these changes on the Centrifuge Facility as described herein.

This report is being issued in three volumes. Volume I & II describe the systems for the initial study divided as described below.

Volume I contains chapters 1-4. These are:

- 1) System Study Overview; 2) Rat Habitat; 3) Squirrel Monkey Habitat; 4) Plant Habitat

Volume II contains chapters 5-9. These are:

- 5) Holding System; 6) Centrifuge System; 7) Glovebox System; 8) Service System; 9) System Study Summary

Volume III contains the Centrifuge System - Node Accommodations Study Results.

The study and report here presented are the result of a team effort. The members of the team with primary responsibility for the contents of this report were:

Patricia Blair
Alan Cartledge
Jorge Garces-Porcile
Vladimir Garin

Mike Guerrero
Peter Haddeland
Mike Horkachuck
Ulrich Kuebler

Frank Nguyen
Marc Murbach
Richard Schaupp
Sidney Sun

Linda Swan
Robert Synnestvedt
Mark Turner
Will Vallotton

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ABBREVIATIONS AND ACRONYMS

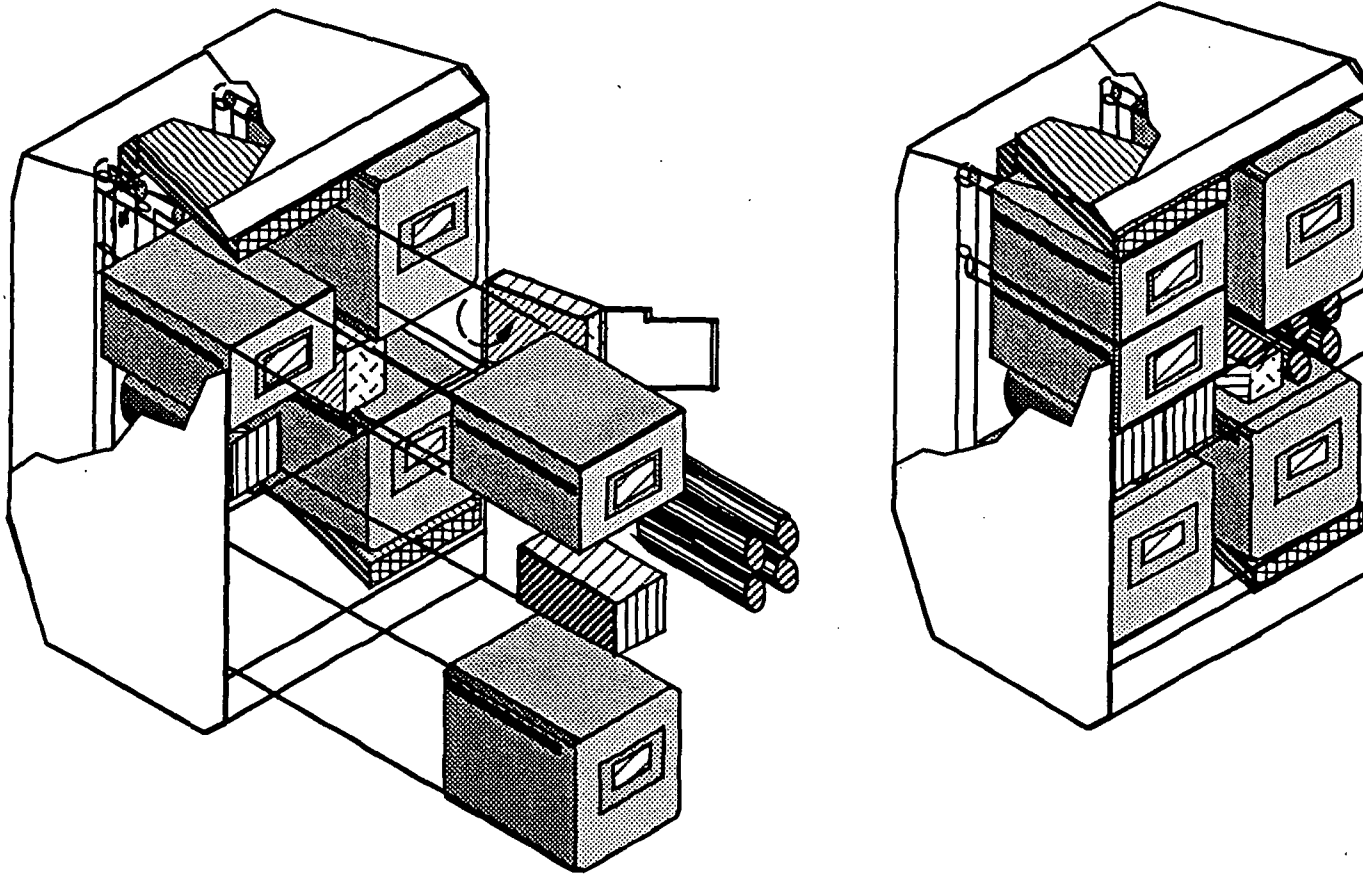
ARC	Ames Research Center
BW	Black And White
CCW	Counter Clockwise
CF	Centrifuge Facility
CFM	Cubic Feet Per Minute
CFU	Colony Forming Units
CRS	Contaminant Removal System
CW	Clockwise
DMS	Data Management System
ECLS	Environmental Control and Life Support
ECS	Environmental Control System
EDP	Embedded Data Processor
HEPA	High Efficiency Particulate Air Filter
HX	Heat Exchanger
IR	Infrared
LED	Light Emitting Diode
LSE	Laboratory Support Equipment
LSG	Life Science Glovebox
MDM	Multiplexer de-Multiplexer
NIH	National Institute of Health

ABBREVIATIONS AND ACRONYMS

NIU	Network Interface Unit
PMMS	Process Materials Management System
PPA	Power Protection Assembly
QD	Quick Disconnect
RAHF	Research Animal Holding Facility
RFP	Request For Proposal
RH	Relative Humidity
SCSU	Specimen Chamber Service Unit
SM	Squirrel Monkey
SMAC	Space Maximum Allowable Concentration
S. S. F.	Space Station Freedom
SWG	Science Working Group
TBD	To Be Determined
TCCS	Trace Contaminant Control System
TIMES	Thermoelectric Integrated Membrane System
U. S. Lab	U. S. Laboratory Module
UV	Ultraviolet
VCDS	Vapor Compression Distillation System

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 5 Habitat Holding System



INTRODUCTION

The chart on the adjacent page presents an outline of the contents of this chapter of the report.

OUTLINE

- Primary Requirements
- System Description
- System Characteristics
- System Interfaces
- Tradeoffs
- Technical Issues/Analyses
- Operations
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PRIMARY REQUIREMENTS

The primary purpose of the Holding System is to provide a microgravity environment in which life science experiments will be performed. Experiments in the Holding System will parallel control experiments on a Centrifuge in orbit as well as Earth based control experiments.

The Holding System in this report is designed for the Space Station Freedom. The design must fit within the structural envelope of a standard 74.5" functional rack with a curved back. Ducting, valves and a Contaminant Removal System provide two way bioisolation between Freedom and the habitats.

To minimize the frequency of disturbances to the specimens, the Holding System must provide resources which support animal habitats for ≥ 14 days and ≥ 90 days for plants between servicing.

PRIMARY REQUIREMENTS

- Support modular habitats for microgravity experiments with rodents, primates and plants in space
- Accommodate ≥ 4 primate or plant habitats or ≥ 6 rodent habitats
- Accommodate mixed habitat types (primates, rodents and plants) simultaneously
- Satisfy Freedom interface requirements
- Constrained to one 74.5" standard double rack
- Satisfy habitat interface requirements
- Maintain environmental control parameters for each habitat
- Provide bioisolation between habitats and Freedom
- Provide water for animals ≥ 14 days without resupply
- Provide water and gases for plants ≥ 90 days without interruption

PRIMARY REQUIREMENTS (CONT'D)

Holding System is a term which refers to integrated subsystems - a Holding Unit and specimen habitats. The Holding Unit is a structure which provides thermal, power, data and fluid resources to support the habitats. The Holding Unit supports habitats which hold squirrel monkeys, rats, and plants as sample specimens.

The habitat support functions have been distributed between the habitats and the Holding Unit. The Holding Unit has a standard interface plate from which the habitat receives necessary resources. This interface plate is common to all habitat support systems. Habitats connect only to resources necessary to support the specimen type within the habitat. The Holding Unit provides a continuous water supply from Freedom to the habitats with a 24 hour reserve. This water supply meets both science requirements for the specimen drinking or hydration source and Freedom requirements for back contamination. Expelled waste water reclaimed in the water separators or purged from the Plant Habitats is collected in waste water tanks for storage before dumping to a Freedom waste management system.

Animal air quality requirements are satisfied by filtering and conditioning cabin air. Temperature and humidity control are provided by the habitats and the Holding System. The Contaminant Removal System processes the habitat exhaust air to meet Freedom cabin air requirements.

Plant Habitats require medical grade CO₂, O₂ and N₂. Freedom will provide medical grade N₂ to the Holding System via a gas line connection in the utility interface at the rack bottom. The Holding Unit regulates the gas flow to meet the habitat requirements. O₂ and CO₂ are each provided through dual tanks pressurized to 100 atmospheres (1500 psi) and regulated to meet habitat requirements.

Freedom electrical power is supplied to Holding System components through a power protection assembly and power conditioner. The power conditioner will convert the incoming Freedom electrical power to comply with the necessary power demands of the various electrical components within the Holding System. Video and RF signals from the habitats are processed by Holding Unit subsystems to meet Freedom data network requirements.

HABITAT INTERFACES

Holding Unit Provides the Following to the Habitats:

- Ultrapure water for 14 days
- Filtered air from the space station cabin at any setpoint between 15 and 35°C
- 99.997% pure CO₂
- 99.997% pure O₂
- 99.997% pure N₂
- Video, RF, data interfaces and processing from the habitats to the space station data network
- Power
- Waste water collection

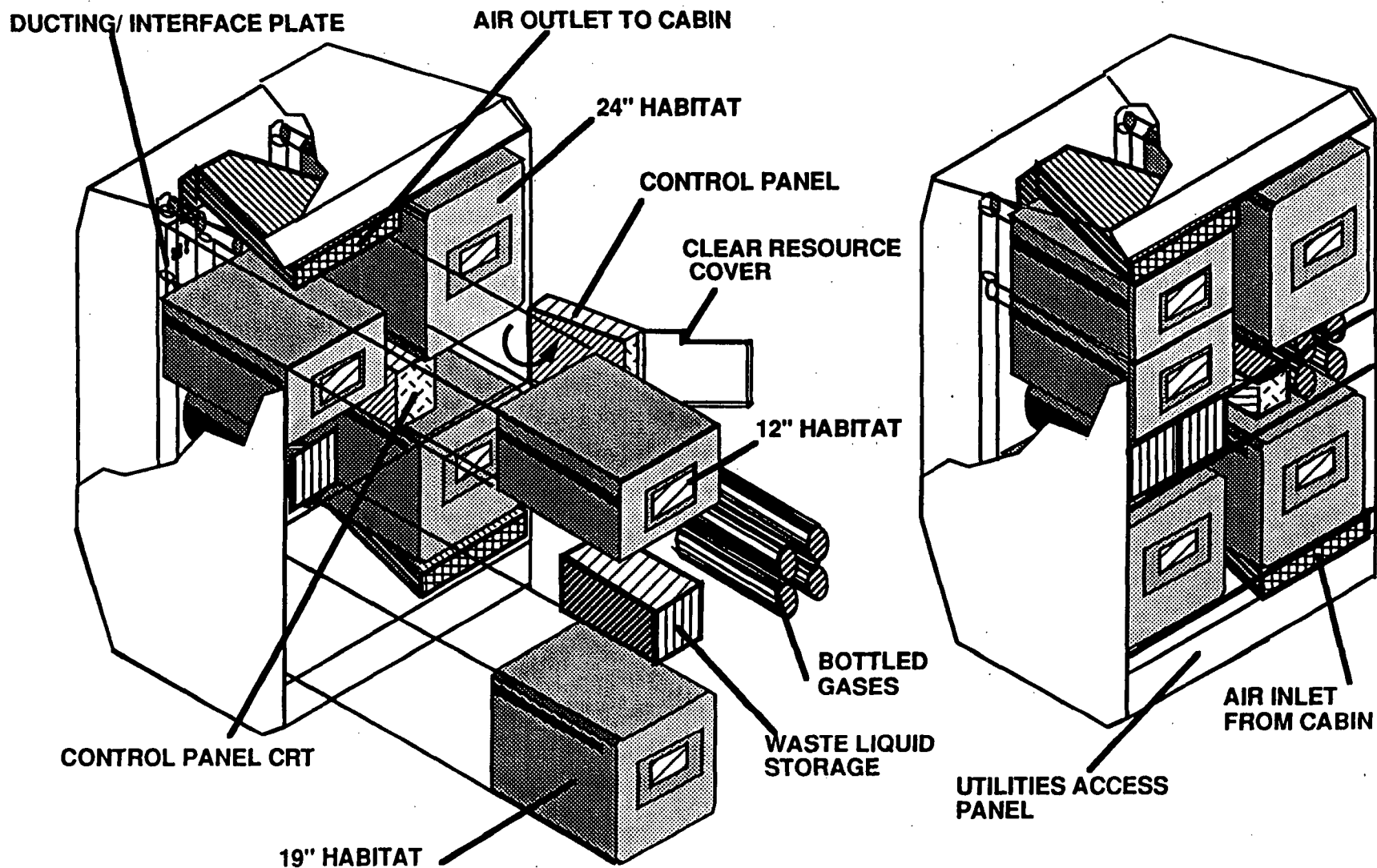
SYSTEM DESCRIPTION

The isometric view of the Holding System on the facing page depicts one possible habitat and resource configuration. The view to the left indicates how habitats and serviceable items are removed from the front of the Holding System and shows the controls location. The control display panel opens as an access door to the gas tanks and to a CRT display.

The air inlet and outlet to the Holding System are located in opposite corners to maximize the distance between them. This reduces the potential for Holding System exhaust air, contaminated with CO₂, from entering the inlet air before being processed by Freedom CO₂ processing systems. The increased distance should aid in diffusing the exhaust air with the cabin air before it returns to the Holding System air inlet.

The right view depicts one arrangement of habitats in the Holding Unit. Habitats can be rearranged or exchanged with the restriction that two stacked small habitats must be removed to place either a medium or large habitat in the remaining void. It should be noted that an installed medium habitat leaves a 13 cm (5 inch) gap between the habitat top and the surface above it.

HOLDING UNIT ISOMETRIC



SYSTEM DESCRIPTION (CONT'D)

The Holding Unit provides the support structure to hold habitats in the microgravity environment of Freedom; other support functions are shared with the habitats. The Holding Unit is also the direct interface between Freedom resources and the habitat. Many design aspects of Freedom continue to change. This in turn changes user interface requirements. The interface requirements in this report are based on the understanding of Freedom as of June 1989.

The thermal control system is based on access to: a 4°C water coolant loop supplied by a Freedom water to water heat exchanger, avionics air ports at the top and bottom of the rack, and heat rejection to the cabin air. All projected heat loads to Freedom fall within the current requirements. The Freedom data management system interfaces with the Holding System via a Network Interface Unit.

The power supply from Freedom is 120VDC.

An ultrapure water supply meets the requirements for both animal drinking water and plant experiments. Cabin air has the same composition as air required for animal experiments. An inlet coarse particulate and HEPA filter remove debris from the inlet air. A temperature and humidity control system conditions the air to meet requirements for each habitat.

Medical grade N₂, CO₂, and O₂ are assumed to be supplied by Freedom. N₂ is supplied through a plumbing line to the rack. O₂ and CO₂ are supplied through an onboard tank storage facility. Tanks from the Holding Unit will be recharged on Freedom.

Freedom waste management systems will be used to process and store waste products from the Holding System. Humidity condensate from the chilled cabin air will be plumbed into a Water Recovery Management System to reclaim usable water. Waste liquids from the waste liquid storage tanks will be plumbed to a Process Materials Management System to reclaim useable water and store waste products for disposal.

SYSTEM DESCRIPTION (CONT'D)

- Used to hold habitats for microgravity experiments in space
- Holds 8 small, 4 medium or 4 large habitats or a mix of sizes
- Conforms to Space Station Freedom standard 74.5" rack envelope
- Uses Space Station Freedom resources
 - Thermal control loop
 - Data management system
 - Power
 - Ultrapure water
 - Cabin air
 - Nitrogen, oxygen, carbon dioxide
 - Process Materials Management System
 - Water Recovery Management System

SYSTEM DESCRIPTION (CONT'D)

The Holding Unit control unit can be accessed through a standard Freedom work station, a Freedom Multipurpose Application Console (MPAC) connected directly to the Holding Unit, or, for critical commands, a miniature display panel and keyboard at the front of the Holding Unit.

Bioisolation between the crew and specimens is maintained with sealed ducting and a negative pressure, relative to the cabin, of all contaminated areas during normal operation of the Holding System.

Freedom is scheduled to operate for up to 30 years. This implies that the Holding System hardware must meet challenging reliability criteria. The hardware must be easily maintained or replaced in the event of a failure or upgrade. The Holding System is designed to allow access to individual components without disturbing others thus facilitating maintenance. To further facilitate maintenance, redundant gas supply tanks, waste liquid storage tanks and contaminant removal canisters have been incorporated into the design. This redundancy permits an item to be replaced without disturbing Holding System operations. It also provides a backup for the system in the event of a failure.

SYSTEM DESCRIPTION (CONT'D)

- Provides habitat monitoring and control
- Provides standard resources through interface plate located at rear of habitats
- Two levels of bioisolation
 - Structural containment via sealed, single pass air loop and HEPA filters
 - Negative air pressure throughout the Holding System ECLS system
- Maintenance
 - Dual tanks for expendables and wastes permit uninterrupted operation during replenishment
 - Easy access provided for units needing routine maintenance
 - Monitoring from the front of the Holding System
 - Waste tanks serviced from the front of the Holding Unit
 - CRS serviced from the rear

SYSTEM DESCRIPTION (CONT'D)

The Holding System is designed to accommodate multiple habitat types simultaneously. Rodent, monkey and plant habitats may all be collocated in the Holding Unit without a change in design to the Holding System configuration. The available resources to the habitats will support all specimen types through use of a common interface plate. The habitat side of the interface plate is configured to connect only to the resource ports which are necessary to support its experiments.

SYSTEM DESCRIPTION (CONT'D)

- Accommodates multiple specimen habitat types simultaneously
 - Study based on rats, squirrel monkeys and plants
- Animal habitat support
 - Conditioned inlet air
 - Single pass environmental control system (no recirculation)
- Plant habitat support
 - Expendable gasses supplied by dual tanks (N₂ supplied through gas line from Freedom)
 - Continuous supply of ultrapure water
 - Collect liquid wastes for transfer to liquid waste storage

SYSTEM DESCRIPTION (CONT'D)

The Holding Unit life support system provides the necessary life support resources to the habitats. The resource connections are the same at each habitat interface. In this way habitat locations may be changed without reconfiguring the Holding Unit.

The life support system supplies air to the habitats, controls inlet air temperature and humidity, processes air before it is exhausted to the cabin, provides liquid storage, and supplies water and gases to the habitats.

LIFE SUPPORT SYSTEM CHARACTERISTICS

- 4700 cc/s (10 cfm) single pass airflow at negative pressure (relative to cabin pressure)
- Controlled temperature within allowable humidity range
- Waste air processing prior to exhaust to cabin
 - CO₂ removal provided by Freedom
- Waste liquid storage
- Ultrapure water supply
- Ultrapure gas supply

SYSTEM DESCRIPTION (CONT'D)

The heavy line in the Life Support Diagram on the facing page indicates the flow of cabin air through the Holding System. Air enters the system through a heat exchanger and air-liquid separator which conditions it to the lowest temperature and humidity level required by the habitats. Valves at each habitat air-inlet control the air flow to the habitats. (Heaters and humidifiers within the habitats adjust the temperature and humidity to the required values.) Air exiting the habitats passes through an air-to-air heat exchanger and an air/liquid separator to reduce moisture content and back through the heat exchanger to increase overall efficiency and move the state-point away from the saturated state.

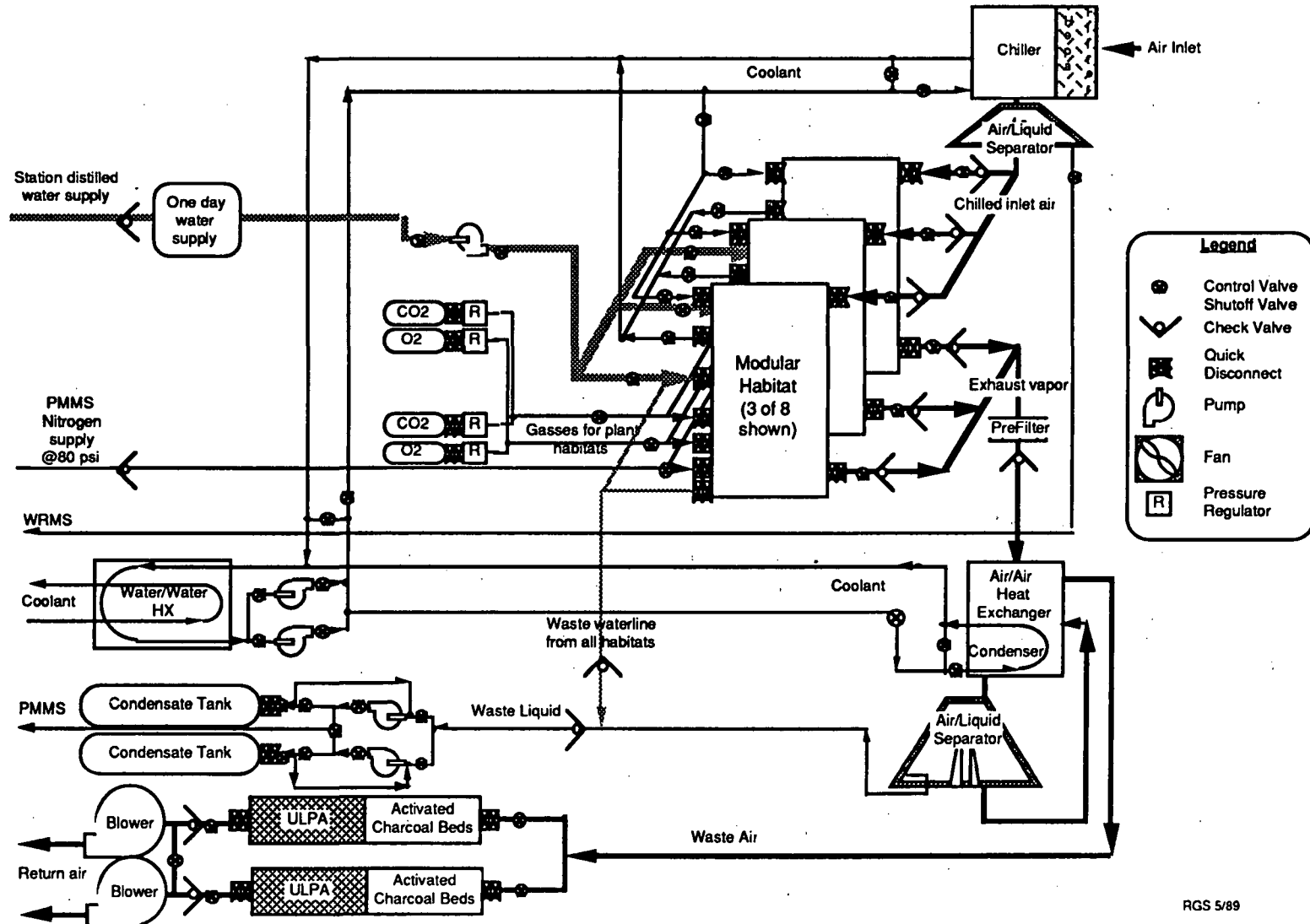
Air is drawn through the system by blowers located at the exit to the cabin thus providing a negative pressure (relative to the cabin) throughout the system. Check valves are located throughout the system to assure one-way flow of air in the system. Quick disconnects isolate the habitats and Holding Unit plumbing from the cabin whenever units (habitats, filters, etc.) are removed from the system. Redundant CRS-HEPA filters and blowers provide the capability to continue operating in the case of a blower failure and allow changeout of filters and CRS canisters while the system is in operation.

Water and gases are supplied to all habitats as indicated by sources to the left of the habitats. Coolant is distributed to all systems which require liquid cooling with a parallel source; all inlets come from a common line and all coolant outlets are plumbed to a common line

Small tanks of pressurized carbon dioxide and oxygen have been incorporated into the design to fulfil Plant habitat requirements. The present design requires tank recharging at intervals of 10 to 90 days depending on the experiment. Nitrogen is supplied directly to the Holding System through a supply line in the Freedom utilities interface panel. This in turn is regulated by the Holding Unit to meet habitat requirements. Redundant pumps fill a temporary reservoir with drinking water from the Freedom utilities interface panel.

LIFE SUPPORT BLOCK DIAGRAM

Holding Facility life support and thermal control systems



RGS 5/89

SYSTEM DESCRIPTION (CONT'D)

Most of the Holding System thermal dissipation is through the Space Station water coolant loop. The Holding System connection to the loop is through a water to water heat exchanger located in the lower portion of the rack. The low temperature coolant from Freedom is supplied at 4°C and the estimated temperature of the coolant on the Holding System side of the heat exchanger at the habitats is 10°C. Coolant is distributed to coldplates on all the components which require substantial cooling. Coolant plumbing in the Holding Unit is parallel (one common inlet and one common outlet) to assure that all habitats have access to the minimum temperature heat sink.

Avionics air is used to cool areas inaccessible by liquid coolant. The avionics air enters the rack through a diffuser in the top of the rack. Avionics air exhausts from the rack through an opening at the bottom of the rack. The design of the Holding Unit permits air passage through the areas which require additional heat removal.

Certain electronic components within the habitats require air cooling. To eliminate the complications in plumbing avionics air to the habitats, cabin air is drawn in through the front of the habitats to cool heat sources within the habitats*. This air is circulated through the habitat electronics compartment and exits into the cabin. It should be understood that this cabin air does not mix with the cabin air used as a life support fluid within the habitat. The areas within the habitat which require separate air types will remain isolated.

* Recent information from the Freedom Program indicates that severe constraints have been placed on cabin air heat loads. Therefore this feature of the design will have to be modified.

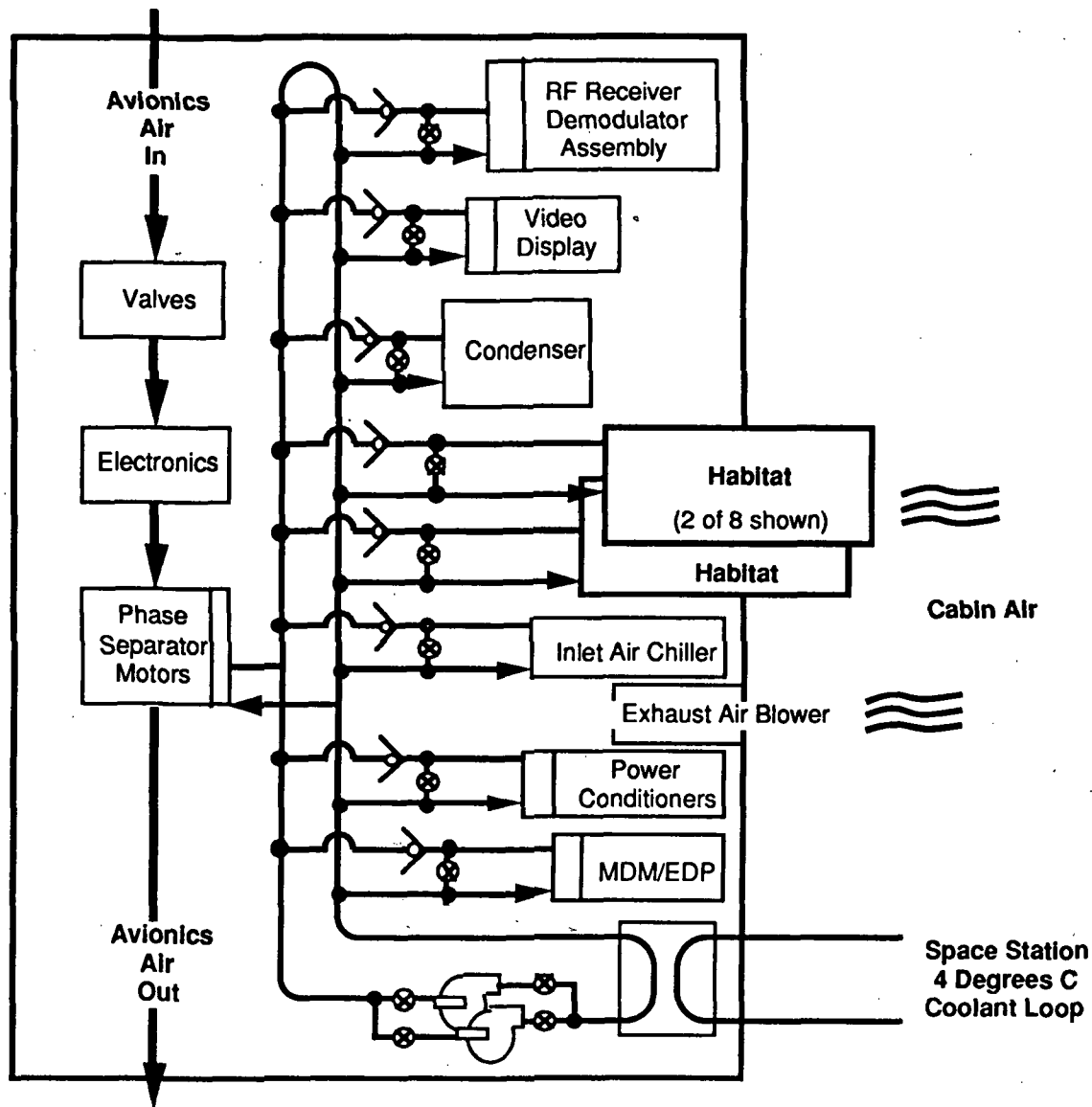
HOLDING UNIT THERMAL SYSTEM

- Coolant loop uses water/water heat exchanger supplied by Freedom
- Thermal control system interfaces with Freedom 4°C coolant loop
- Holding Unit coolant circulates through :
 - Air/water heat exchangers (inlet air chiller and condenser)
 - Water jackets for liquid separators
 - Habitats
 - Coldplates attached to MDM computer, power electronics, video monitor, RF rec/demod assembly
- Avionics air circulates through the rack to provide supplementary cooling
- Projected heat outputs for holding system
 - 87 watts to cabin air and 276watts from habitats
 - 277 watts to avionics air
 - 880 watts to coolant from Holding Unit, 464 watts from habitats and TBD from inlet chiller

SYSTEM DESCRIPTION (CONT'D)

The primary method of removing heat from the Holding System is through a liquid coolant loop connected to the Freedom 4°C loop by a liquid-to-liquid heat exchanger. Avionics air is used for some units as shown by the heavy arrows on the left side of the figure. Some heat is removed by air returned directly to the cabin as shown by the wavy lines.

THERMAL BLOCK DIAGRAM

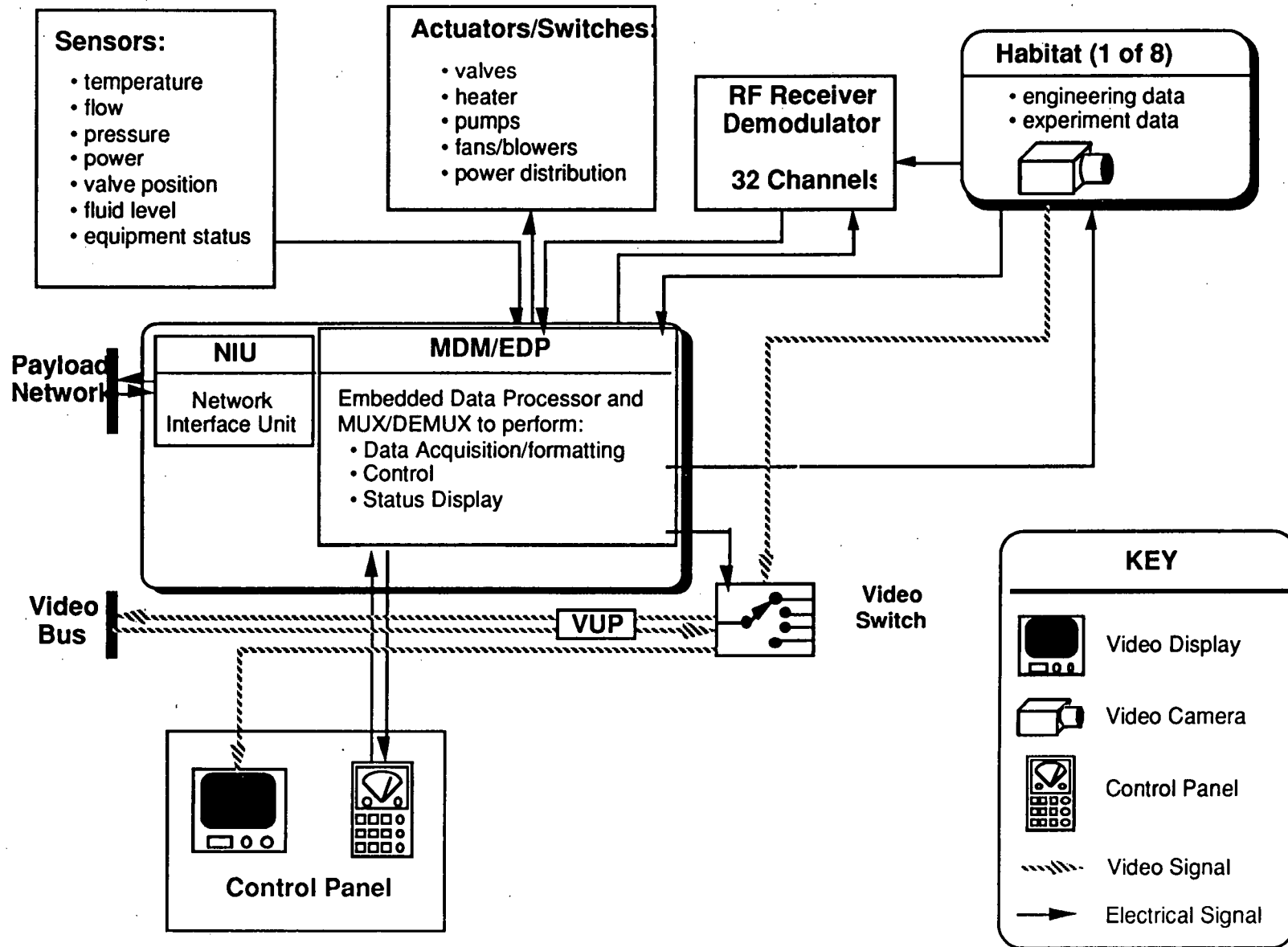


SYSTEM DESCRIPTION (CONT'D)

The central controller for data collection, packaging and transmission is the Freedom supplied MDM. Experiment specific cards are inserted into the MDM to perform required tasks. As shown in the figure on the facing page, the MDM controls all sensors, actuators and switches, and serves as the interface between the payload network and the Holding System.

(It should be noted that the EDP (Embedded Data Processor) has been deleted from the Freedom program subsequent to completion of the study. This feature of this design will have to be modified in future studies).

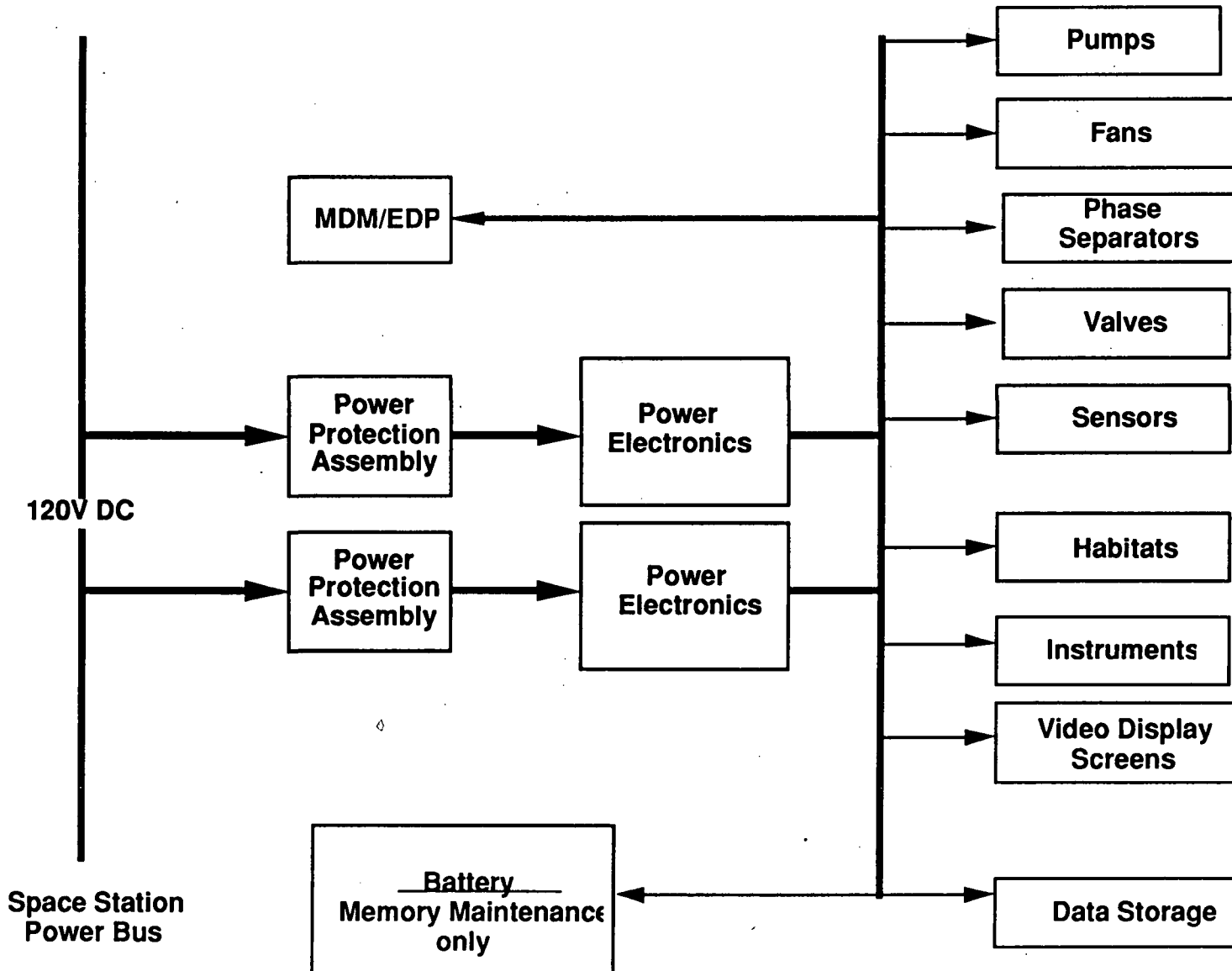
DATA BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

Freedom supplies electrical power to users at 120 Vdc. The Holding Unit converts this power supply to 28 Vdc power for fans, blowers and other mechanisms and 110 Vac power for mechanisms or lights requiring ac power. After conversion, the power is distributed to all electrical components.

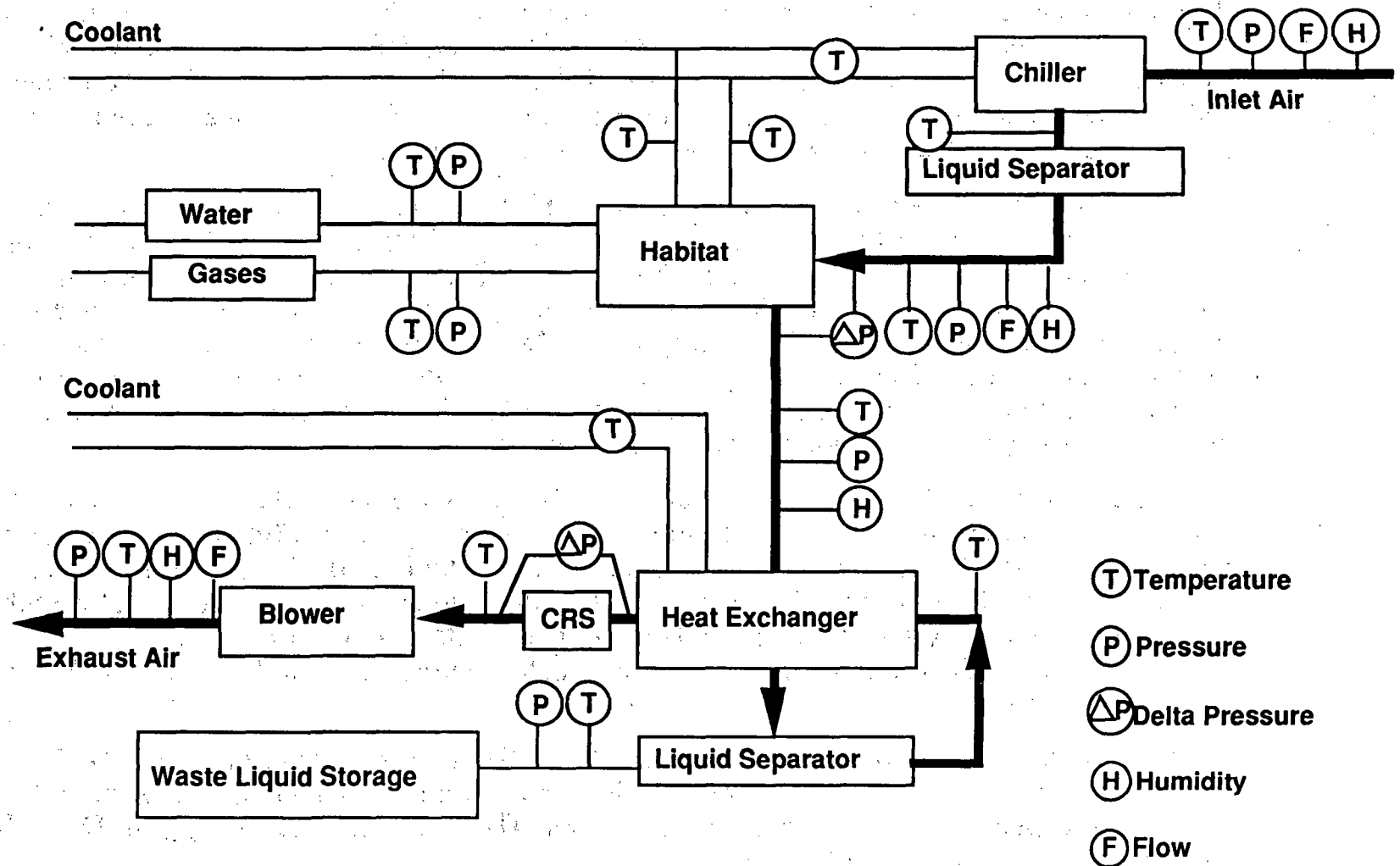
ELECTRICAL BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

Four types of sensors (pressure, temperature, humidity and flow rate) are used throughout the system to monitor conditions within the system and status of resource tanks and filters. Information from the sensors is used to control environmental conditions and determine maintenance intervals.

INSTRUMENTATION BLOCK DIAGRAM



SYSTEM CHARACTERISTICS

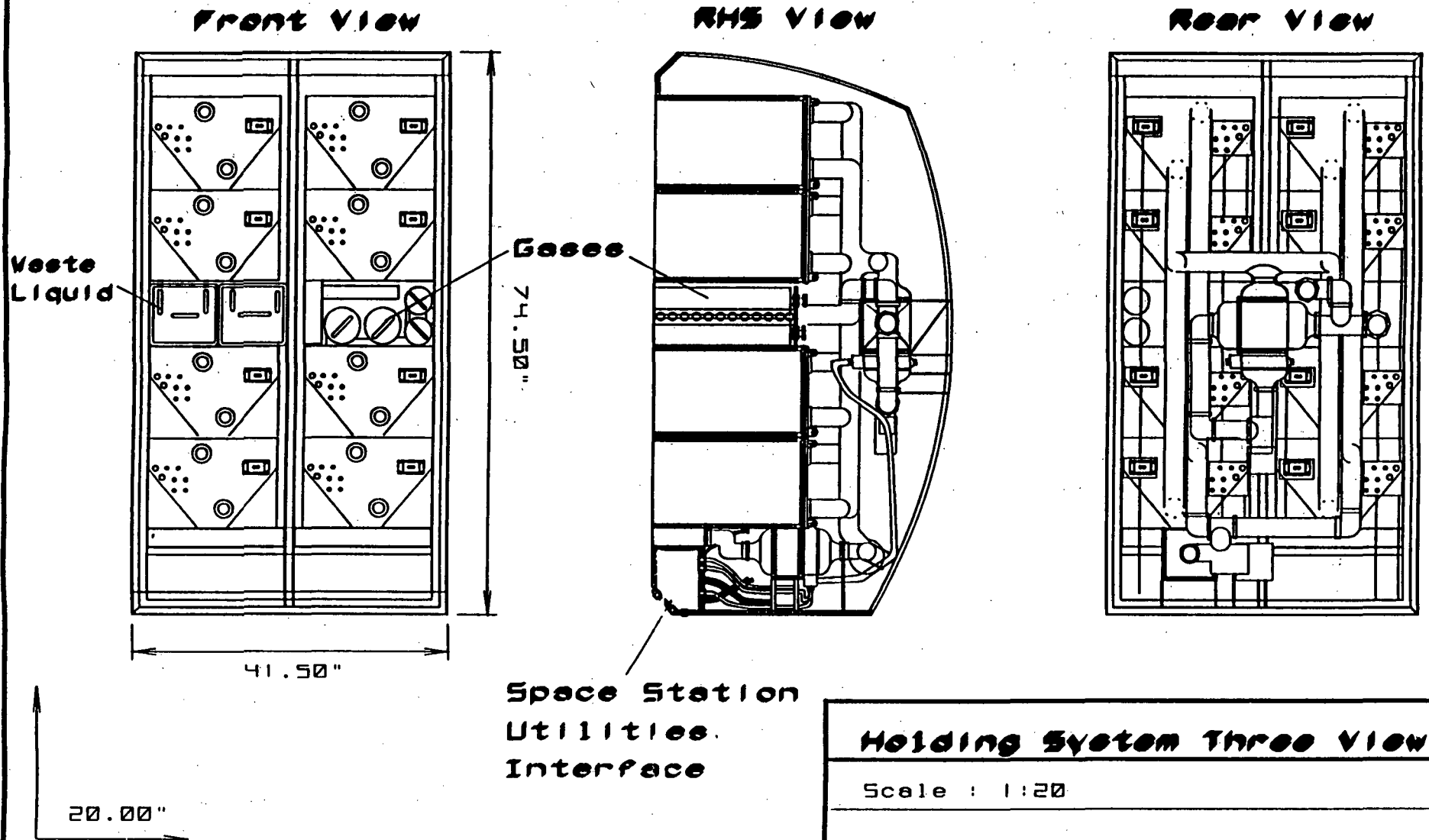
The front view of the Holding Unit depicts the locations of the interface plates, waste liquid storage tank and gas tanks. The series of eight small circles on the left hand side of the interface plates indicate the eight fluid line connections between habitats and the Holding Unit. The two large circles indicate the air inlet (upper) and outlet (lower) connections. The rectangular cluster on the right hand side of the interface plate depicts the power and data connector.

The waste water storage tanks are located in front of the Holding Unit to facilitate servicing and to provide easy access for maintenance in the event of the need for manual waste water purging. The baseline concept uses a direct purge to the PMMS. Quick disconnects at the rear of the tanks connect to a plate in the Holding Unit. Two large oxygen and two small carbon dioxide tanks are located on the right hand side of the Holding Unit. The gas tanks are attached to the Holding System via quick disconnects. The Holding System controls are located in the gas tank alcove. A door (not shown) swings away to provide access to the alcove. The door acts both as a cover to the gas tank alcove and as a support for a system status display screen.

The Holding Unit shell conforms to a standard 74.5" rack envelope. The center support strut acts both as rack reinforcement and attach point for various subsystems. Structural reinforcement for habitat mounting is depicted in the right side view. Habitat to Holding System attachment mechanisms would be integrated into this substructure. These mechanisms are electromechanical worm drives which screw into a threaded hole in the habitats. A motor rotates the drive shaft which in turn draws the habitat into the recess. A trip switch is activated when the habitat is flush against the interface plate.

The utility access panel and stay-out zone is located in the front bottom of the rack. The dimensions in the right view are to scale. The rear view indicates where the remaining hardware and ducting are located (depicted in the drawings which follow). The main duct sizes are 2.5 in ID and branch ducts to the habitats are 1.5 in ID.

HOLDING UNIT SECTION VIEW



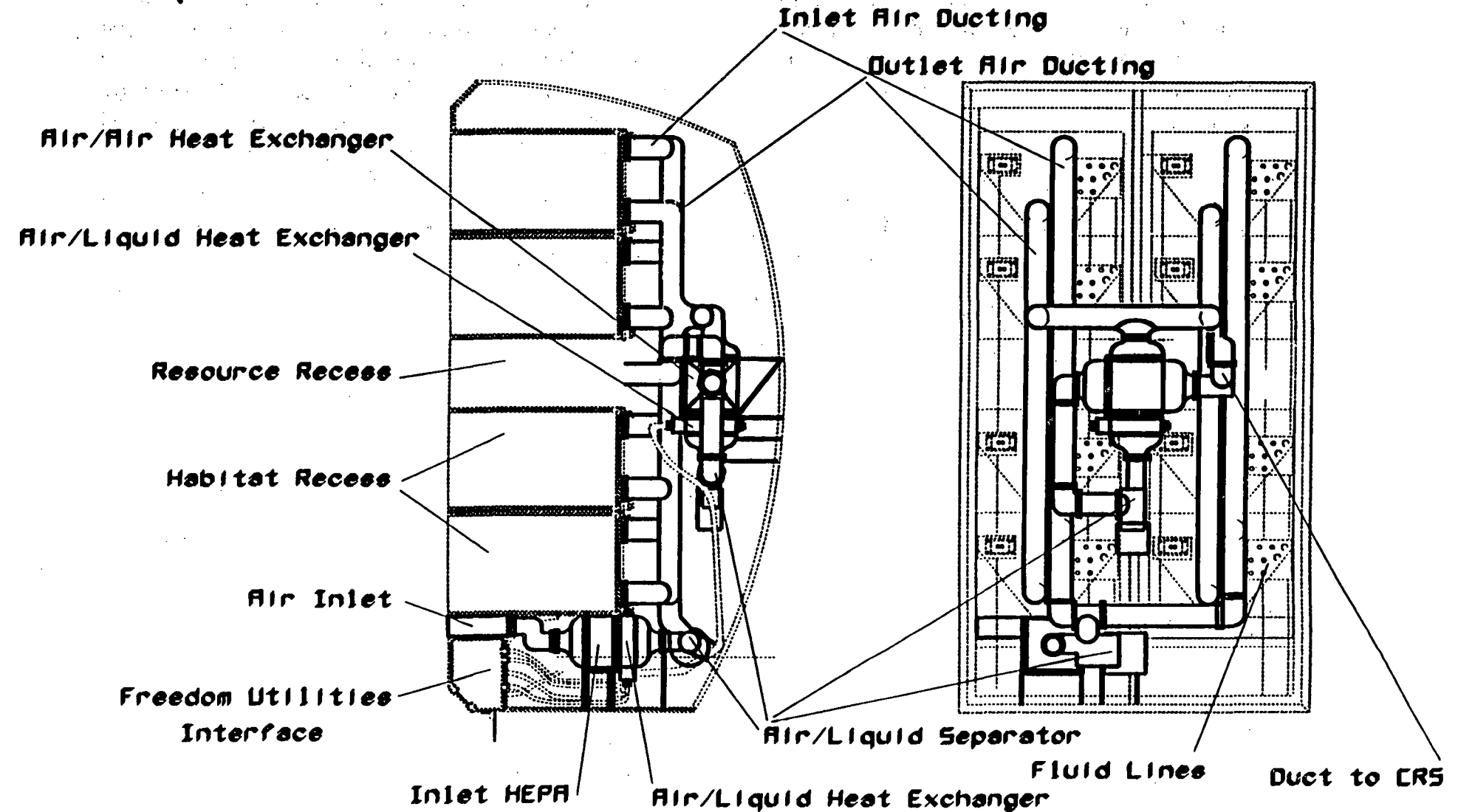
SYSTEM CHARACTERISTICS (CONT'D)

Cabin air is drawn into the Holding System through a filtered vent in the front lower right corner above the utility interface and below the lowest habitats. This inlet vent is shown in the lower left hand corner of the right view. To access the air inlet filter the lower right habitat must be removed and a sealed access port removed. The filter is sized to last over 90 days to reduce the frequency of this procedure.

Downstream of the inlet filter is an air/liquid heat exchanger and separator as seen in the right view. Any water condensed in the separator is plumbed back to the water reclamation management system onboard Freedom. The plumbing is not shown.

Air exiting the inlet air/liquid separator divides into two habitat air inlet ducts which run vertically to the habitats. This duct is shown in the rear view - right side of the figure. The air circulates through the animal habitats and exits into outlet ducts which combine to transport waste air to a waste liquid separator. En route to and exiting from the waste liquid separator is an air to air heat exchanger. This heat exchanger aids in cooling the air before entering the liquid separator and reheats the exiting air to meet Freedom requirements before exhausting to the cabin. In the rear view the air to air heat exchanger is depicted as a square.

HOLDING UNIT HABITAT AIR DUCTING

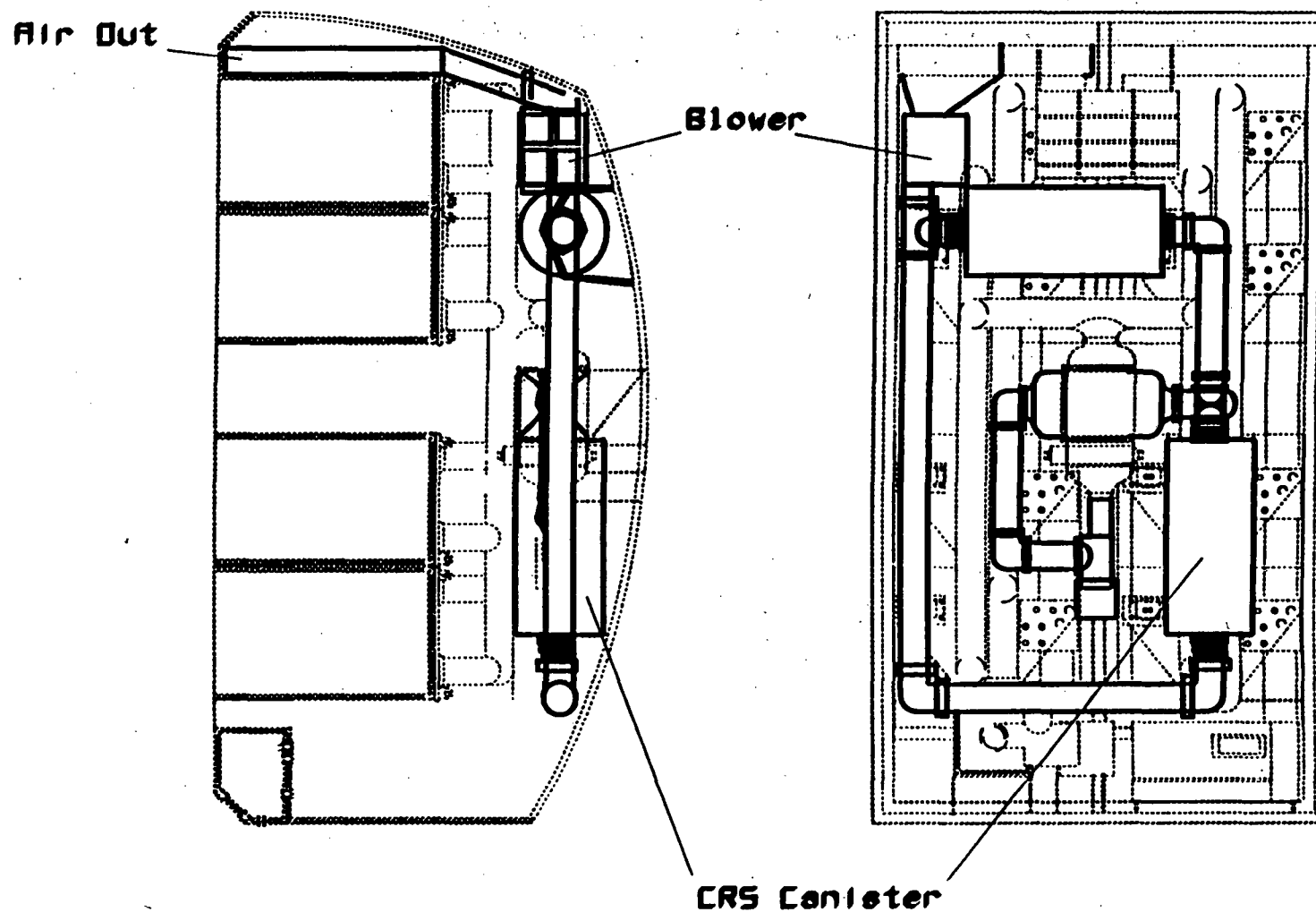


SYSTEM CHARACTERISTICS (CONT'D)

Waste air from the air to air heat exchanger is directed to one of two paths which lead to Contaminant Removal System (CRS) canisters. These systems remove the remaining waste products from the habitat waste air and condition the air to meet Freedom requirements. A three way valve at the exit of the air to air heat exchanger controls the air flow to the two CRS. Normal operation uses one CRS until it must be replaced. Airflow is directed into the second CRS allowing replacement of the first CRS without interruption to the experiments. The CRS canisters are attached to the exit ducting with valves which serve to maintain bioisolation during servicing operations.

The final stage of the air ducting is a redundant two stage blower. Exhaust air blows through a diffuser at the upper right side of the Holding System as shown in the right view. A coarse particulate filter at the outlet prohibits debris from entering the air outlet.

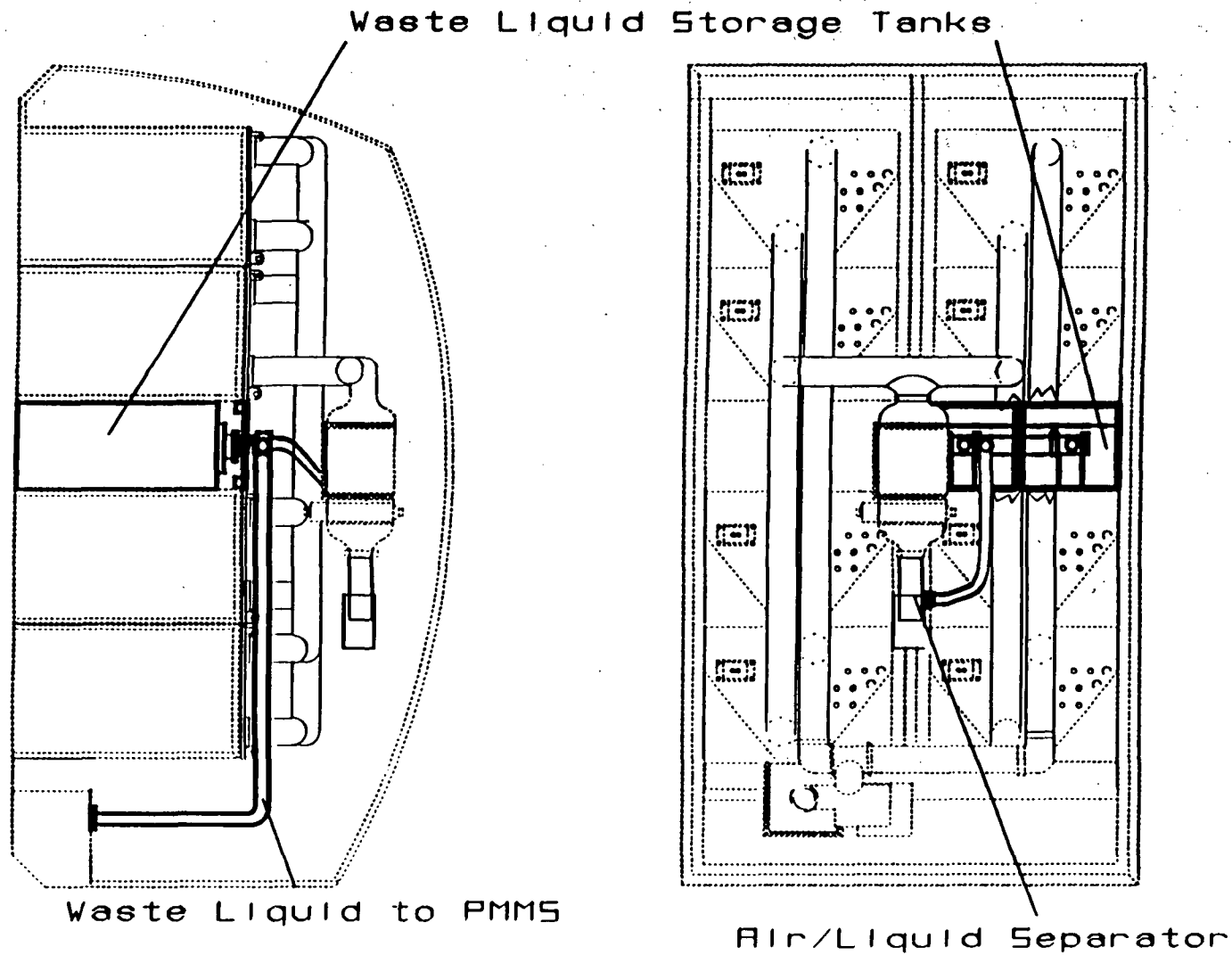
CRS AIR DUCTING (REAR)



SYSTEM CHARACTERISTICS (CONT'D)

Waste liquid from the waste liquid separator is plumbed to waste liquid tanks located at the front of the rack. The tanks are pressurized to provide the compressive force to purge waste into the PMMS. To facilitate manual tank purging, the tanks connect to the Holding Unit with quick disconnects. The tanks are redundant to facilitate maintenance without interruption to the experiments.

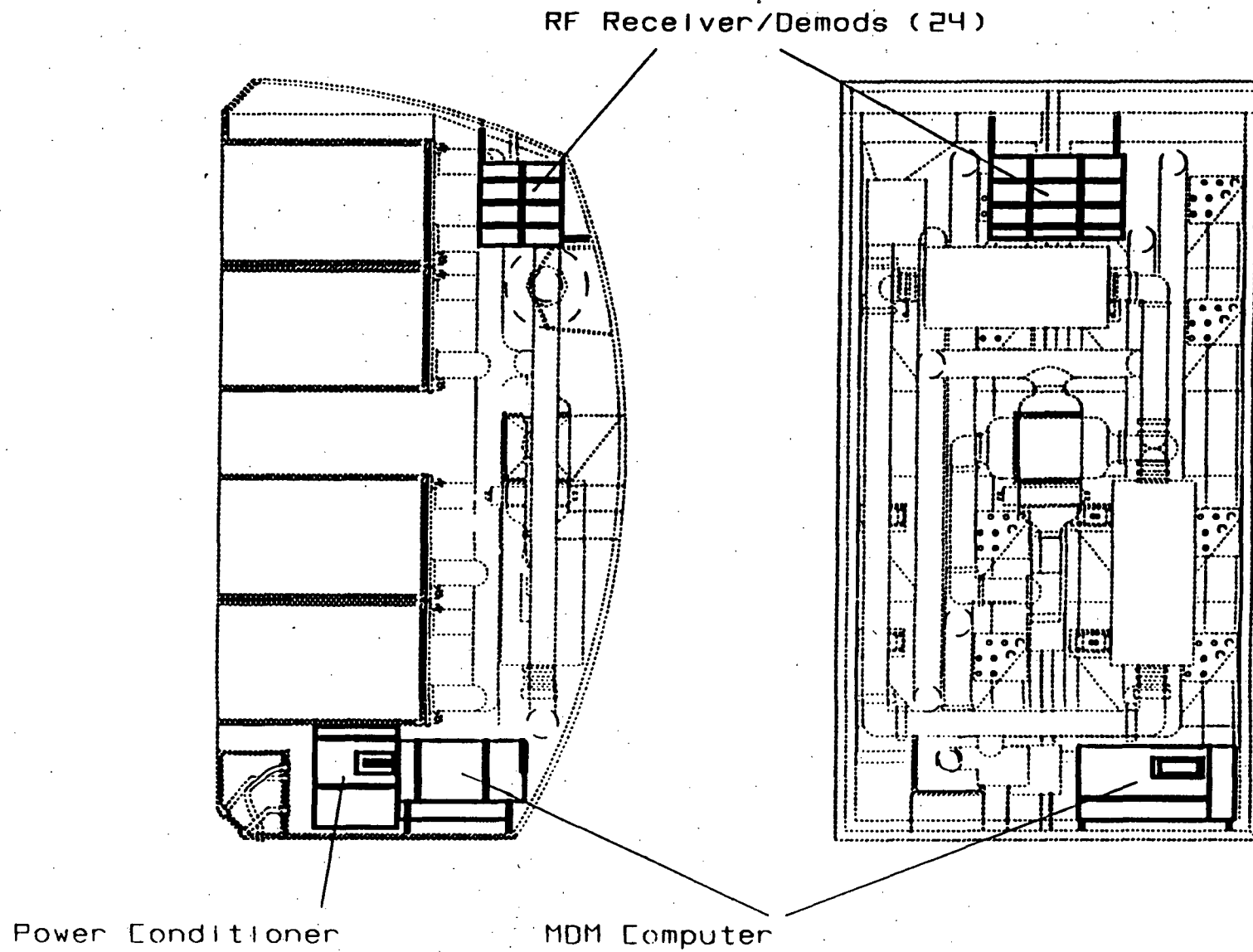
LIQUID WASTE STORAGE (FRONT)



SYSTEM CHARACTERISTICS (CONT'D)

The electronics necessary to support Holding System functions are depicted on the facing page. The power protection assemblies, power conditioner and MDM are located in the lower left corner of the Holding Unit. In addition, 32 receiver/demodulator units which are required to receive data transmitted by an RF link from sensors implanted in animals are mounted in the Holding Unit. Co-location of these units facilitates servicing.

ELECTRONICS LOCATION



SYSTEM CHARACTERISTICS (CONT'D)

These tables list the mass and volume estimates for the major subsystems within the Holding System. The sources of these estimates are listed in the right hand column. **Freedom** indicates that the value was supplied by Freedom documentation. **Catalog** indicates that the value was listed in a catalog for a similar component. **Calculated** indicates that the value was calculated from past experience or other data. **Rough** indicates that a value was based on estimates. Under 'Life Support Consumables' the dry masses refer to the resource containers; the wet masses refer to expendable resources. The gas tank estimates were from a catalog for high pressure vessels used in aircraft. The resource calculations are summarized further into the report.

HOLDING UNIT MASS/VOLUME ESTIMATE

	Mass	Volume	Basis for value
	kg (lb)	m ³ (ft ³)	
Life Support Containers (dry mass)	37 (82)	0.11 (4.10)	
- gases	20 (44)		Catalog
- water	3 (8)		Calculated
- storage tanks	14 (30)		Calculated
Life Support Consumables (wet mass)	75 (165)		
- gases	3 (6)		Calculated
- water	3 (6)		Calculated
- filters	27 (60)		Calculated
- storage tanks	42 (93)		Calculated
Instrumentation	minimal in subsystems		
- humidity			
- temperature			
- pressure			
- flow			
Electronics	152 (334)	0.12 (4.08)	
- MDM Computer	17 (37)		Freedom
- power conditioner	36 (80)		Calculated
- power protection assembly	20 (44)		Freedom
- wire harness	27 (59)		
- RF receiver demods	19 (43)		Calculated
- video	9 (20)		Calculated
- controller / keyboard	14 (30)		Rough Est
- data storage	9 (20)		

SYSTEM CHARACTERISTICS (CONT'D)

No structural analysis was performed for this report. To provide a rough estimate of mass for the Holding Unit structure the Freedom rack mass was doubled to account for secondary structure.

The percent of allocation shows the mass and volume of the Holding Unit relative to the mass carrying capability (400 Kg) of the standard rack and to the nominal volume for experiments (one cubic meter). However, with the addition of secondary structure, mass capability can be increased to 700 Kg. Volume in excess of one cubic meter is available by using the curved rear section of the rack. The total volume estimate includes a 25% contingency.

HOLDING UNIT MASS/VOLUME ESTIMATE

	Dry Mass kg (lb)	Volume m ³ (ft ³)	Basis for value
Thermal Systems	25 (55)	0.04 (1.31)	
- water/water heat exchanger	12 (26)		Freedom
- water/air heat exchanger	10 (22)		Catalog
- air/air heat exchanger	3 (7)		Rough Est
Powered Mechanisms	42 (95)	0.02 (0.62)	
- liquid separators	18 (40)		Exist Hdwr
- blowers	2 (4)		Catalog
- pumps	14 (30)		Exist Hdwr
- seating mechanisms	8 (17)		
Ducting and Plumbing	65 (140)	0.10 (3.58)	Calculated
Structure	123 (270)	0.01 (0.52)	
- primary	62 (135)		Freedom
- secondary	61 (135)		Rough Est
Sub totals	520 (1140)	0.41 (14.8)	
25% Design Contingency	650 (1425)	0.51 (18.5)	
Percent of allocation (% of 400kg launch mass and 1m ³)	163 %	50 %	
8 Rodent Habitats	254 (560)	0.55 (19.3)	
Total with habitats	906 (1985)	0.96 (34.1)	
Percent of total allocation		100 %	

SYSTEM CHARACTERISTICS (CONT'D)

The facing page is a table of estimated power requirements to operate the Holding System.

HOLDING UNIT POWER ESTIMATES

	Average Power (watts)	Source of Heat Rejection
Liquid Separators (2)	168	coolant
Blowers	150	cabin air/avionics air
Pumps (3)	112	coolant loop
MDM Computer	85	coolant loop
RFReceiver demodulators (24)	96	coolant loop
Power electronics	419	coolant loop
Control electronics/video	120	avionics air
Miscellaneous	94	avionics air
Subtotal without habitats	1,244	
Habitats (4 plant habitats)	740/1224*	coolant loop/cabin air
Total power	1984/2468*	
Total with 25% design contingency	2480/3085*	

*peak power (lights on)

SYSTEM CHARACTERISTICS (CONT'D)

The large variance in data rates for the animals is due to the type of experiments which may be performed. The high data rates come from experiments which require high frequency response to monitor specimen activities such as muscle electrical impulses. The data rates required to monitor and control environmental parameters are negligible when compared to the science experiment requirements.

HOLDING UNIT DATA RATES

	Data Rates (kbps)	
Engineering data	4 to 6	
Science data		
Rodent Experiments (8 Habitats)		
Nominal	2000	
Maximum		5424
Primate Experiments (4 Habitats)		
Nominal	1405	
Maximum		4437
Plant Experiments (4 Habitats)		
Nominal	2	
Maximum		5
Maximum System data rates	5430	
Internal Video channels	2 channels/hab	
Video to Freedom (after multiplexing)	1 channel	

SYSTEM INTERFACES

The facing page provides a list of Freedom resources necessary to operate the Holding System. These items were described in detail in preceding charts.

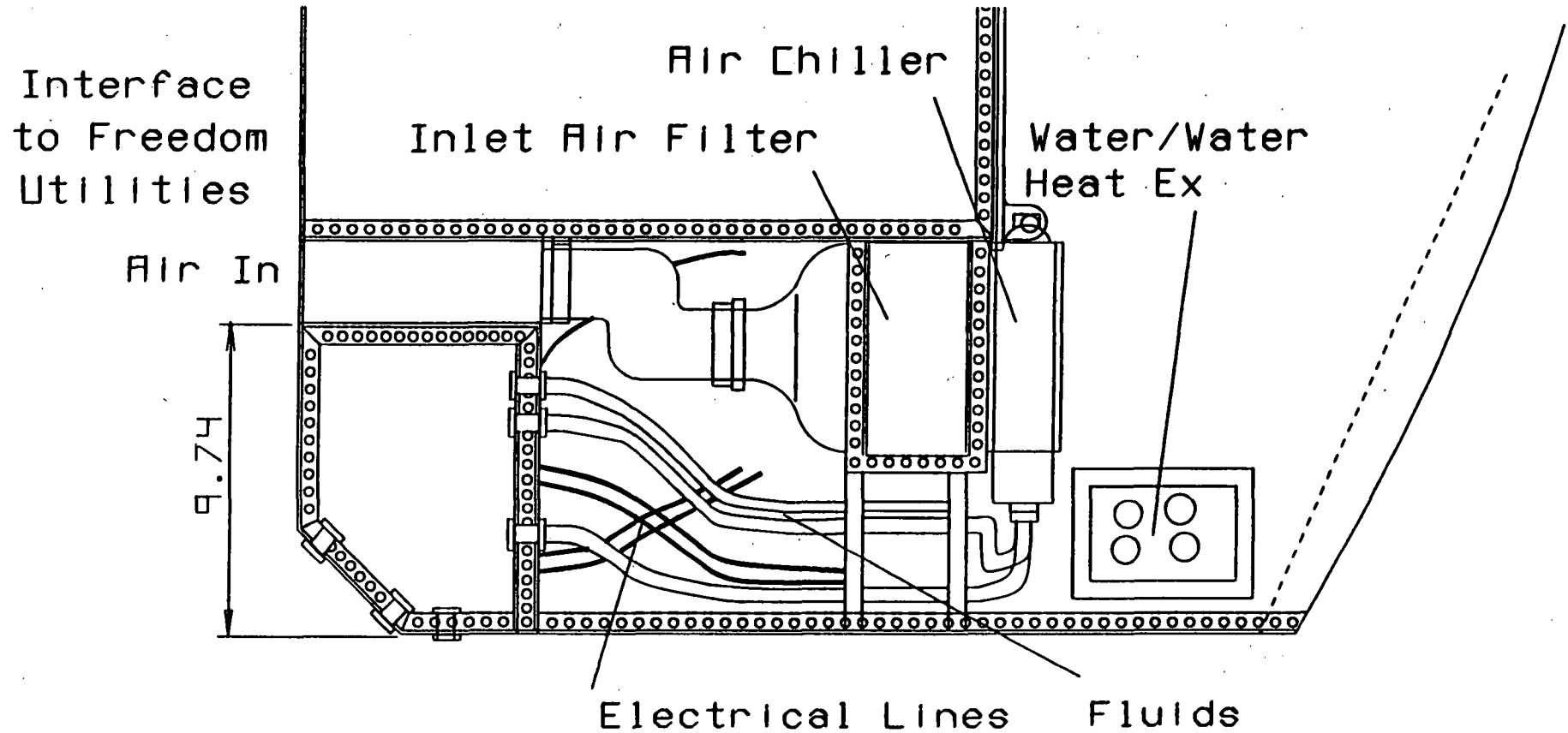
SYSTEM/FREEDOM INTERFACES

- Power (120 Vdc)
- Data (video, payload network)
- 4°C coolant loop (water/water heat exchanger from Freedom)
- Avionics air loop
- Fire detection/suppression (requires Freedom definition)
- Cabin air
- Water Reclamation Management System (reclamation of cabin humidity condensate)
- Process Materials Management System (for liquid waste processing)
- Ultrapure water
- Gases
 - Nitrogen (direct line from Freedom)
 - Oxygen (recharge tanks at Freedom tank farm)
 - Carbon Dioxide (recharge tanks at Freedom tank farm)

SYSTEM INTERFACES

The facing page shows a side view of the Freedom utility interface to the Holding System. From this access panel all resources, except cabin air and avionics air, are supplied.

FREEDOM UTILITY ACCESS DETAIL



TRADEOFFS

A number of top level tradeoffs at the beginning of the study were necessary to determine which functions were to be provided by the Holding Unit and which by the habitats. Furthermore, the common interface plate layout and the habitat sizes underwent several design iterations before suitable designs were selected. The Holding Unit design was based on the results of the top level tradeoffs. Three Holding System tradeoffs are listed on the facing page, and discussed in subsequent pages. Some of the tradeoffs are common with the Centrifuge as indicated.

The tradeoffs are presented in terms of advantages (+) and disadvantages (-). The + and - symbols are qualitative and are not to be tallied to determine the quantitative merits of each option.

TRADEOFFS

- Centrifuge and Holding Unit Common Tradeoffs
 - Independent vs. shared air controls
 - Thermoelectric vs. liquid coolant
 - Interface plate connector
- Holding System Layout
 - Holding Unit habitat and resource location
 - Holding Unit controls location
- Front access of Contaminant Removal System(CRS) vs Waste Liquid Storage

TRADEOFFS

The facing table shows the key points considered in evaluating various approaches for supplying respiration air to the habitats. These tradeoffs are the same for the Holding Unit and the Centrifuge. The shared control would use a manifold to duct common inlet air to all habitats. The independent inlet air control would provide individual ducts to each habitat from individual sources. The decision was to provide shared control.

CENTRIFUGE AND HOLDING UNIT TRADEOFF

Independent vs. Shared Inlet Air Control for Habitats

Independent Inlet Air Controls	Shared Inlet Air Control
<ul style="list-style-type: none">+ Maximum flexibility in controlling inlet conditions to the habitat+ Component failure affects only respective habitat- Reduces volume available for habitats- Too many lines across rotary joint on Centrifuge- Connections, structural attachments, plumbing, valving etc. in 8 locations complicates servicing	<ul style="list-style-type: none">- Must cool system inlet air to lowest required temperature and reheat/humidify at habitats- Component failure could effect all habitats+ Economy of scale saves mass and volume+ Provides greater volume for habitat accommodation

Current Choice: Shared inlet air control to maximize volume available to habitats.

TRADEOFFS

The facing table shows the tradeoffs considered in evaluating various approaches for controlling temperature within the habitats. These tradeoffs are common to the Holding Unit and the Centrifuge. The decision was to use liquid cooling as this was readily adapted to the interfaces with Freedom, and required less power.

CENTRIFUGE AND HOLDING UNIT TRADEOFF

Thermoelectric vs. liquid coolant thermal control system

Thermoelectric unit	Liquid coolant loop with heat exchangers
<ul style="list-style-type: none">+ Accurate temperature setting- Large power consumption- Large volume for each unit- Low reliability	<ul style="list-style-type: none">- Subject to corrosion and liquid leakage+ Low power consumption for pumps+ Compact and light+ High reliability

Current Choice: Coolant loop will transfer thermal load into Freedom thermal loop and help alleviate severe power constraints.

TRADEOFFS (CONT'D)

This tradeoff examined the Habitat-Centrifuge, Holding Unit and Glovebox locking mechanism design and location. Two locations and two types of mechanisms were considered. Features considered were access to habitats, visual access to the connectors during mating, connector alignment and mating forces. The mechanism selected requires single-handed operation capable of exerting a significant force to overcome the resistance of multiple connections. The electrical connector is specified as 100 lbs. maximum for 250 cycles.

The front locking system is similar to that used to lock RAHF cages into Spacelab racks. Levers, with a cam system, provide a mechanical advantage for the operator who locks the habitats into place. Disadvantages of this system are that the force exerted by an operator to lock in a habitat may exceed the NASA standards' limits and the load path of this force may require additional structure and weight in each habitat.

The rear locking system uses a motor drive, a gear reduction, and a low pitch, threaded rod to provide mechanical advantage. The motor could provide a high torque at low velocity to reduce disturbances during the mating process. The large forces would be restrained to the two plates on which the connectors are mounted. A disadvantage of this design is lost volume to accommodate a large pin which must penetrate into the habitat. Another disadvantage is the potential for cross threading while threading the insert into the habitat. A geared shaft to the front of the rack could be turned to provide the same function as the motor if power or the motor were to fail. A ratchet or electric drill could be used to torque the geared shaft.

The rear locking motor driven mechanism was selected for this study, however new options for mechanisms should be explored.

CENTRIFUGE AND HOLDING UNIT TRADEOFF

Habitat Locking Mechanism

Front Locking/Manual

- + Easy access to mechanism
- Forces too great for manual operation
- Force is through whole habitat. Would require additional structure
- Difficult alignment- guide pins and tight tolerances likely

Rear Locking/Motor Driven

- Limited access to mechanism
- + Forces overcome by motor drive with high gear reduction
- + Force is restrained within interface plate
- + Can be used to facilitate connector alignment
- + Override is provided using ratchet wrench or power driver

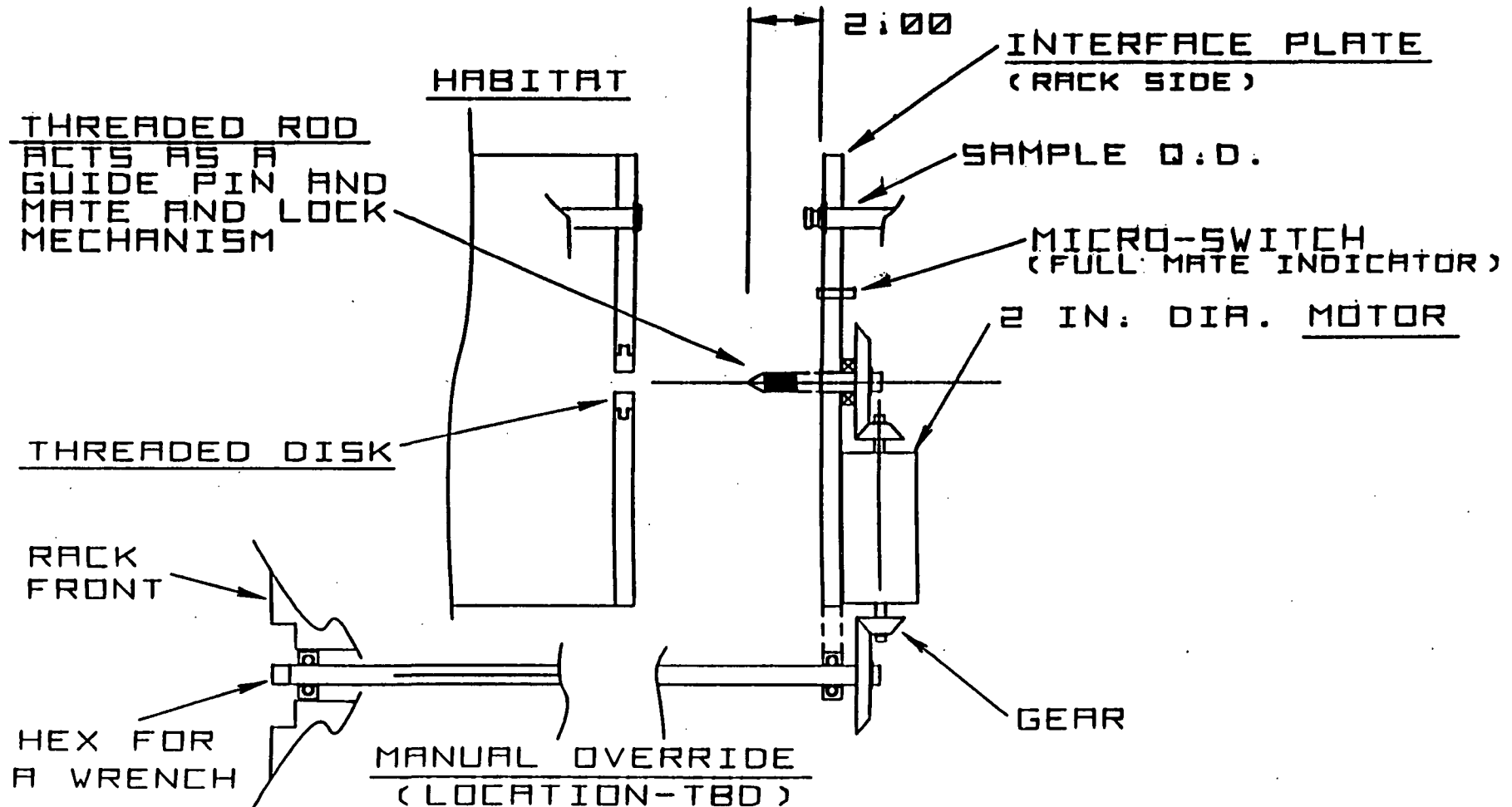
Current Choice: The rear locking and motor driven locking mechanism.

TRADEOFFS (CONT'D)

The facing page shows a side view of the interface plate mating mechanism to be attached to the Holding Unit (right side of the figure) and how it would interface with a Habitat. The threaded guide acts both as mechanism to provide the mating force and align the floating interface plate with the fixed connections on the Habitat.

HABITAT LOCKING MECHANISM

INTERFACE PLATE MATING MECHANISM



HOLDING UNIT TRADEOFF (CONT'D)

The tradeoff shown on the following figure leads to a baseline for which the gas tanks are located to provide front access with redundant CRS canisters and waste liquid storage tanks. Location of the CRS canisters and waste liquid storage tanks is addressed in a separate tradeoff--see pages 66 and 67.

HOLDING UNIT TRADEOFF (CONT'D)

Holding Unit habitat and resource location

Resource location options	Configuration impacts	Selected option/comments
Front access to all expendables facilitates crew operations	Will eliminate volume for habitats	Do not locate all expendables at front of holding unit
Front access to gas tanks facilitates crew operations	Habitat arrangement is not effected by gas tank location	Locate gas tanks in front of holding unit
Redundant CRS and waste liquid storage permit uninterrupted operation during resource resupply	Significant volume used by redundant CRS and waste liquid tank	Provide redundant CRS and waste liquid storage, experiments require uninterrupted operation
Front access to both CRS and waste liquid storage tanks eliminates need to tilt Holding Unit forward for resupply	Front access to both CRS and waste liquid storage tanks eliminate one habitat location	Do not provide front access to both CRS and waste liquid tanks, perform additional tradeoffs

Current Choice:

- Locate gas tanks at front of holding unit
- Provide redundant CRS and waste liquid storage tanks
- Tradeoff between CRS and waste liquid storage front access addressed in separate tradeoff

HOLDING UNIT TRADEOFF (CONT'D)

NASA STD 3000 Human Interface Accommodations specifies allowable locations for crew operated systems. The controls for the Holding System would reduce the number of habitats the Holding System could support if they were located at the specified height for a crew member in the neutral body position. A tradeoff between the controls location and overall configuration impacts to the Holding System was performed.

The left column of the table on the facing page indicates three choices for the controls location. The center column indicate the impacts to habitat accommodation due to the controls location and the right hand column indicates the choice made in the tradeoff.

The decision for the tradeoff is listed in the box at the bottom of the facing page.

HOLDING UNIT TRADEOFF (CONT'D)

Holding Unit controls location

Resource / controls options	Configuration impacts	Selected option/comments
Location of controls at 3/4 rack height is ideal for crew interface	Location of controls at 3/4 rack height partitions habitat recess such that one large or medium habitat could not be accommodated	Do not locate controls at 3/4 rack height
Location of controls at top or bottom of Holding Unit make crew operations cumbersome	Controls at top or bottom of Holding Unit consolidate habitat location which increases usable volume	Do not locate controls at top or bottom of Holding Unit because of crew constraints
Location of controls at mid height of Holding Unit facilitates crew operations without great compromise to habitat accommodation	Separation of habitats complicates resource routing for habitat accommodation	Locate controls at mid height of Holding Unit as a compromise solution

Current Choice: Locate controls at Holding Unit mid height to improve habitat accommodation with minimum compromise to JSC 3000 human interface requirements

HOLDING UNIT TRADEOFF (CONT'D)

Waste liquid storage tanks and contaminant removal system (CRS) canisters are both large units. The CRS canisters will require routine changeout. The requirement for changeout of the waste tanks is dependent on whether or not there will be a direct, plumbed interface to the PMMS. If changeout is required for the liquid waste tank, it will be more frequent than for the CRS canisters. Therefore, it was decided to place the waste tanks in the front of the rack and the CRS canisters in the back.

Note that the '+' and '-' symbols are qualitative and are not to be tallied to determine the quantitative merits of each option.

HOLDING UNIT TRADEOFF (CONT'D)

Front access to CRS vs. waste liquid storage tanks

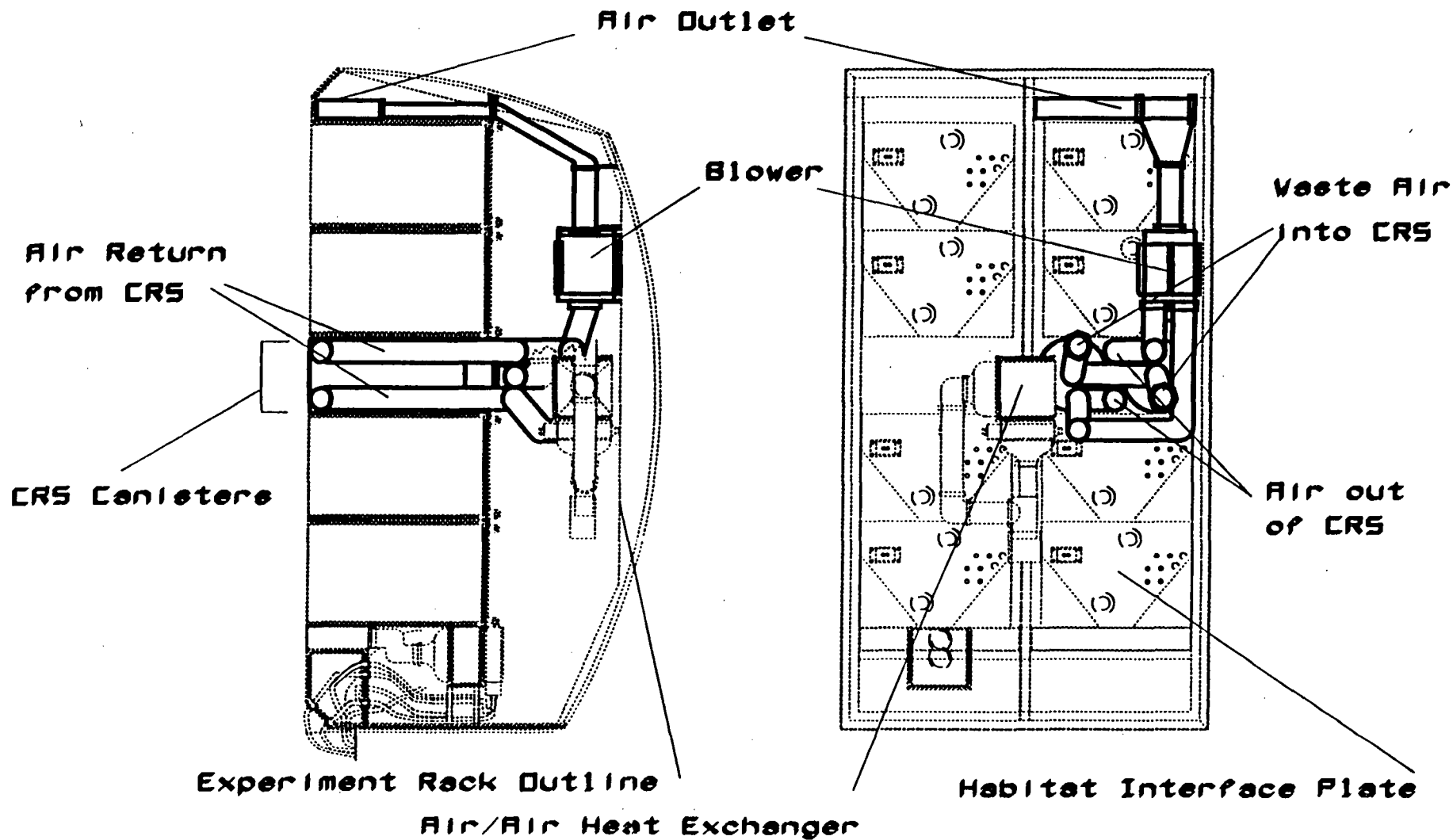
Contaminant Removal System (CRS) front access	Waste Liquid Storage Tanks front access
<ul style="list-style-type: none"> + Minimal disturbance to replace expended CRS + Facilitates crew operations for CRS replacement - Necessitates placement of liquid waste storage in rear of Holding Unit - Complicates ducting route from air/air heat exchanger to CRS + If Centrifuge Facility has a direct interface to the PMMS there is no reason to remove waste storage tanks under normal operation 	<ul style="list-style-type: none"> + Minimal disturbance to remove full waste liquid tank + Facilitates crew operations for waste tank replacement/serving in case of failure - Necessitates placement of CRS in rear of Holding Unit - Difficult to place CRS in rear of Holding Unit due to severe volume constraints associated with duct routing - If Centrifuge Facility has a direct interface to the PMMS removal of waste storage tanks is not required during normal operation

<p>Current Choice: Waste liquid tanks should be placed in front of Holding Unit to avoid possible redesign layouts if CF has no access to PMMS</p>
--

HOLDING UNIT TRADEOFF (CONT'D)

As an alternative to the baseline design, the Contaminant Removal System could be located in the front of the Holding System as shown on the facing page. This would provide more useable volume in the rear of the Holding System for ducting, insulation, electronics, and the fire suppression system at the expense of crowding the ducting to and from the CRS.

CRS AIR DUCTING (FRONT)

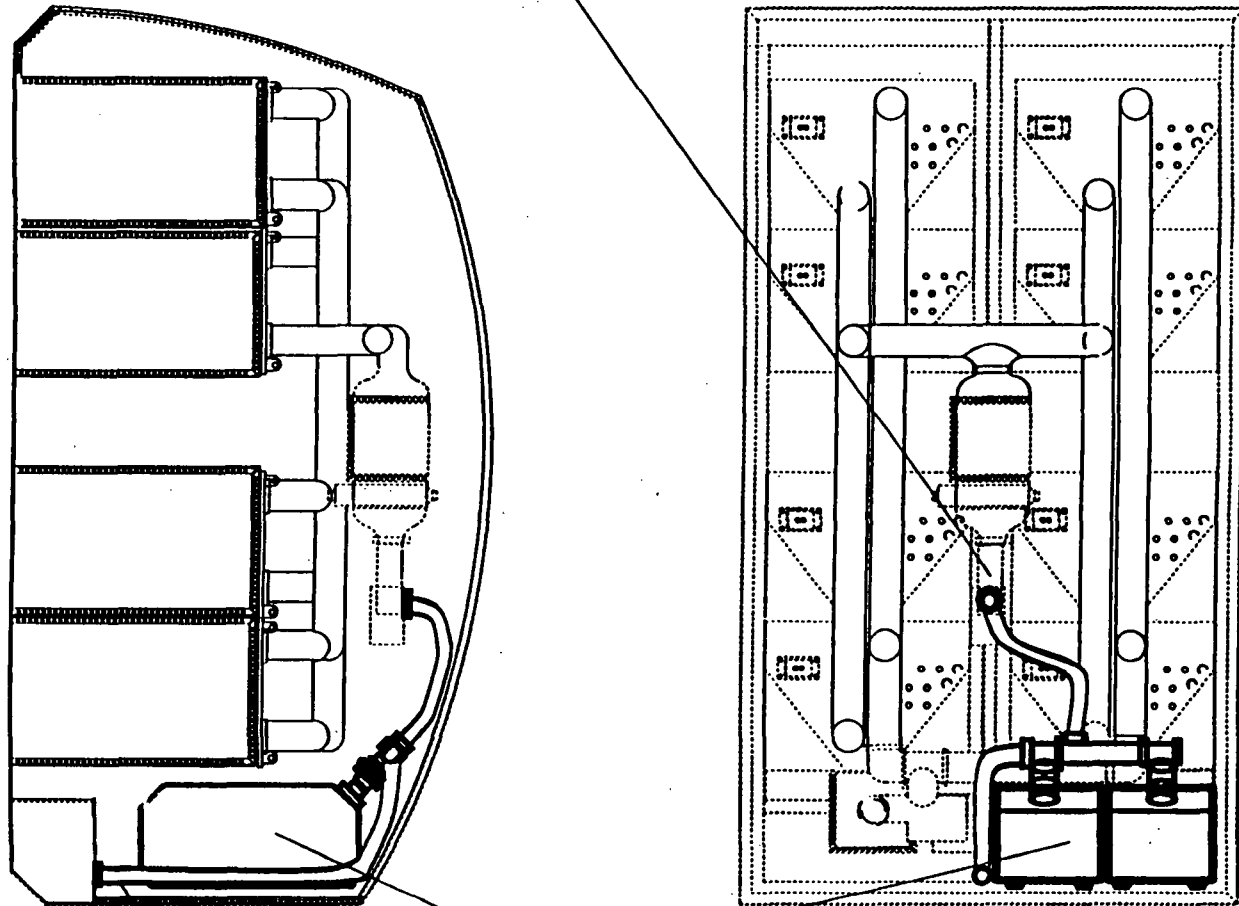


HOLDING UNIT TRADEOFF (CONT'D)

As an alternative to the baseline design the waste liquid storage tanks could be located at the bottom of the rack as shown on the facing page. This would decrease the distance to plumb the waste liquid into the PMMS.

LIQUID WASTE STORAGE (REAR)

Air/Liquid Separator



Waste Liquid
to PMMS

Waste Liquid Storage Tanks

TECHNICAL ISSUES AND ANALYSES

The control of biological materials (bioisolation) to prevent cross contamination between the crew and research specimens is an important requirement on the system design.

BIOISOLATION

- Two layers of bioisolation maintained during nominal operation
 - Negative pressure in contaminated ducting is considered as one layer of bioisolation
 - Sealed construction with filters at inlet and outlet provides one layer of bioisolation
- Large CRS lowers servicing intervals between replacement
- Redundant CRS lowers risk of failure due to connecting and disconnecting
- Filtered reservoir for water storage on the Holding Unit reduces risk of back contamination into Freedom water supply

TECHNICAL ISSUES AND ANALYSES

The design characteristics of materials for the CRS are shown on the following page. The design is based on a mission dedicated to a total load of 48 rats with CRS changeout at 45 day intervals. The mission contaminant load values were calculated based on contaminant load models for animals from life sciences studies. Calculations of the amount of the various chemicals required for the total estimated load are based on empirical studies by Dr. Ted Wydeven of NASA Ames. As a check on the approach, a geometric scaling of the General Purpose Work Statement (GPWS) Trace Contaminant Central System (TCCS) for the design mission model was conducted. This analysis led to the same CRS size.

CONTAMINANT REMOVAL SYSTEM (CRS)

Filtration	Contaminant	Absorber requirement (gm/rat/day)	Mass per CRS (gm)	Time between servicing (days)
Activated charcoal	odors	0.1875	405	45
Charcoal impreg with H ₃ PO ₄	ammonia	2.153	4650	45
2% Platinum	CO and H ₂	0.833	40	45
Purafil™	odors	0.011	24	45

Note: The CRS canister is 20 cm (8") in diameter by 45 cm (18") long. The CRS includes a HEPA filter with the same diameter by 7.5 cm.(3") deep. Each CRS unit is sized for the maximum contaminant load rate (based on accommodation of 8 habitats each with 6 rats). Each canister is sized to last 45 days.

TECHNICAL ISSUES AND ANALYSES

Based on certain assumptions for the type of experiments to be performed with plants, values for O₂ and CO₂ consumption were calculated. The large consumption rate of N₂ depends on the current plant habitat design which adjusts the concentration of O₂ within the habitat by varying the percent of N₂. Therefore, assuming an atmospheric content of 20% O₂, the N₂ must be added to the habitat as shown.

Because CO₂ liquifies at a pressure of 67 atm (1000 psi) at room temperature, a tank pressure of 100 atm (1500 psi) was baselined to assure that CO₂ was stored as liquid. Liquifying the CO₂ reduces the tank volume.

The waste water storage capability for 14 days (two tanks each with 7 day storage) was based on the requirement to have animal experiments operate for up to 14 days before servicing.

STORAGE TANKS CHARACTERISTICS

Resource	Requirements (gm/day/habitat at STP)	Mass at 100 atm (gm)	Days between tank servicing
CO ₂	22	1096	50
O ₂	3.2	685	200
N ₂	90.0	888	10

Resource	Requirements (ml/rat/day)	Mass per tank (gm at STP)	Days of storage
Drinking water	60	2880	1 day reserve
Waste water storage	60	40320	14 day reserve with option to dump to PMMS

Note: The water storage is based on accommodation of eight rodent habitats with six rodents in each habitat. It has been determined that this is the worst case load for water storage.

The gas tanks are pressurized to 100 atmospheres (1500 psig) at room temperature. The gas consumption rates come from Cary Mitchell assuming 20% oxygen by volume in the habitats.

The Holding System depends upon a direct nitrogen supply line from the Space Station resources.

TECHNICAL ISSUES AND ANALYSES

Animals are supplied with air for respiration by inlet ducting (shown earlier). The exhaust air from the habitats carries with it the CO₂ respired from the animals at a rate of at least 10 air changes per hour. A nominal airflow rate of 4700 cubic centimeters per sec (10 cfm), which corresponds to a low rate of 470 cc/s (1-2 cfm) for each habitat, was selected to reduce system penalties associated with higher airflow rates.

HABITAT AIRFLOW RATE

- Low airflow rate 4700 cc/s (10 cfm) is system baseline
- Meets science requirements of >10 air changes/hr per habitat (provides 50-100 air changes per hour)
- High airflow rejected due to acoustic noise, power and ducting/component volume penalties associated with it
- Low flow rate makes temperature and humidity control more difficult
- Operation at higher airflow rates within science requirement limits does not effectively entrain waste

OPERATIONS

The following five 'Operational Scenarios' list steps taken in operations with the Holding System.

Habitat removal and insertion is bound to be the most frequent operation performed. The time between changes will vary. The facing page lists the typical steps taken in performing this operation.

OPERATIONS

Habitat removal (as required)

- i - Shut control valves between habitat and Holding Unit
- ii - Engage habitat release mechanism and remove habitat
- iii - Attach transporter unit to rear of habitat
- iv - Take habitat to destination

Habitat insertion

- i - Detach habitat from transporter
- ii - Slide habitat into empty access port
- iii - When habitat has been aligned with mating mechanism, engage connections
- iv - Check status of habitat and system

OPERATIONS (CONT'D)

Removing the Contaminant Removal System canisters may be cumbersome. For this reason they have been sized to last for many weeks. Note that replacement of the canisters requires tilting the rack forward.

The steps taken to remove a canister are listed on the facing page

OPERATIONS (CONT'D)

CRS Removal (rear access every 45 days)

- i - Acquire clean CRS from supply and bring to holding unit**
- ii - Open valves to CRS#2**
- iii - Shut valves between CRS#1 and holding unit**
- iv - Check status of system to assure proper operation with CRS#2**
- v - Tilt rack forward to provide access to expended tank from rear**
- vi* - Engage release mechanism and remove CRS#1**
- vii - Insert new CRS#1**
- viii - Tilt rack back and continue normal operation**

*** bag out procedure is required**

OPERATIONS (CONT'D)

If the Holding System cannot be plumbed directly to a Freedom waste processing system then the crew will need to replace the liquid waste tanks periodically (approximately every 7 days).

The steps taken in replacing waste storage tanks are listed on the facing page.

OPERATIONS (CONT'D)

Waste Tank Removal (front access every 7 days)

- i - Acquire empty waste tank from supply and bring to holding unit
- ii - Open valves to waste tank#2
- iii - Check status of system to assure proper operation with waste tank#2
- iv - Shut valves between waste tank#1 and holding unit
- v - Engage release mechanism to remove waste tank#1
- vi - Release waste tank#1 and insert new waste tank
- vii - Check status and continue normal operation

OPERATIONS (CONT'D)

The frequency of gas tank replacement to support plant experiments depends greatly on the experiment. Although there are experiments which may last 45 days with very little gas exchange, there are reference experiments that require large volumes of gas which in turn requires frequent gas tank replenishment.

The steps used in removing the gas tanks are listed on the facing page.

OPERATIONS (CONT'D)

Gas Tank Removal (front access every 10-45 days)

- i - Shut valves between gas tank and holding unit
- ii - Check status of system to assure proper operation with remaining gas tank
- iii - Engage release mechanism to remove gas tank
- iv - Take gas tank to Freedom tank farm and recharge with pressurized gas
- v - Insert recharged tank
- vi - Check status

OPERATIONS (CONT'D)

An inlet HEPA filters is included in the Holding System design to assure the cleanliness of air delivered to the research specimen.

The steps used in replacing the inlet air filter are listed on the facing page.

OPERATIONS (CONT'D)

Inlet HEPA filter replacement (90 days)

- i - Remove lower right side habitat
- ii - Clamp filter waste bag into place
- iii - Undo filter fastening clamps
- iv - Slide filter into waste bag
- v - Heat seal waste bag
- vi - Unclamp filter waste bag
- vii - Insert new filter
- viii - Check status

TECHNOLOGY DEVELOPMENT

The Holding System is viewed as a system which requires little technological development. Areas which may require development are listed on the facing page. The development of quick disconnects and valves which can maintain bioisolation, do not burden the system with large pressure drops, and have short length will be required. Also, the reliability of liquid separators must increase to maintain efficient operation over a long term.

TECHNOLOGY DEVELOPMENT

- Develop reliable quick disconnects to provide bioisolation
- Develop short length vs diameter valves
- Develop reliable liquid separators for long term operation

REQUIREMENTS NOT MET / CONCERNS

The study identified one requirement not met by the baseline Holding System design, i.e., maintenance of two levels of bioisolation during all operations. In addition, several areas requiring further study and/or testing were identified as shown on the facing page.

REQUIREMENTS NOT MET / CONCERNS

The following requirements have not been met by the current system concept:

- Two levels of bioisolation during all operations
 - One level during CRS changeout

Concern requiring further study/testing

- Vibration and acoustic noise levels
- Cleanability of all contaminated volume (i.e., ducting)
- Reliability and effective operation of liquid separators
- Long term degradation of quality of water supply
- Effectiveness and life cycle of quick disconnects in maintaining bioisolation
- Cleanability and servicing time

SUMMARY

The Holding System design presented in this report would meet the requirements for providing resources for habitats in a microgravity environment. The technology to meet this requirement has already been demonstrated in existing systems. This demonstration includes both space hardware and commercially available hardware.

To fit all the necessary hardware to support the required number of specimens in one double rack will be difficult. There are factors such as the sizing of the waste liquid storage tanks which may help alleviate this problem. If the Holding System were to be plumbed directly to a Freedom waste processing system, then storage volume within the Holding System could be reduced. This would be useful in two respects. The first would be the provision of useful liquid to the waste processing system. Useable water could be extracted from the waste and the waste stored in a large Freedom waste storage tank conveniently located for serviceability. The second advantage to purging waste liquids to a Freedom processing facility is the increased volume this provides on the Holding System for other subsystems.

This system has been designed for Space Station Freedom as baselined prior to June 1989. The numerous support functions and resources provided by Freedom makes development of a Holding System feasible. Should these functions be reduced, the design presented here would be impacted and the experimental capabilities would need reducing to make the system feasible. If the resources are provided, a Holding System similar to that which has been presented would provide resources for habitats in a controlled microgravity environment.

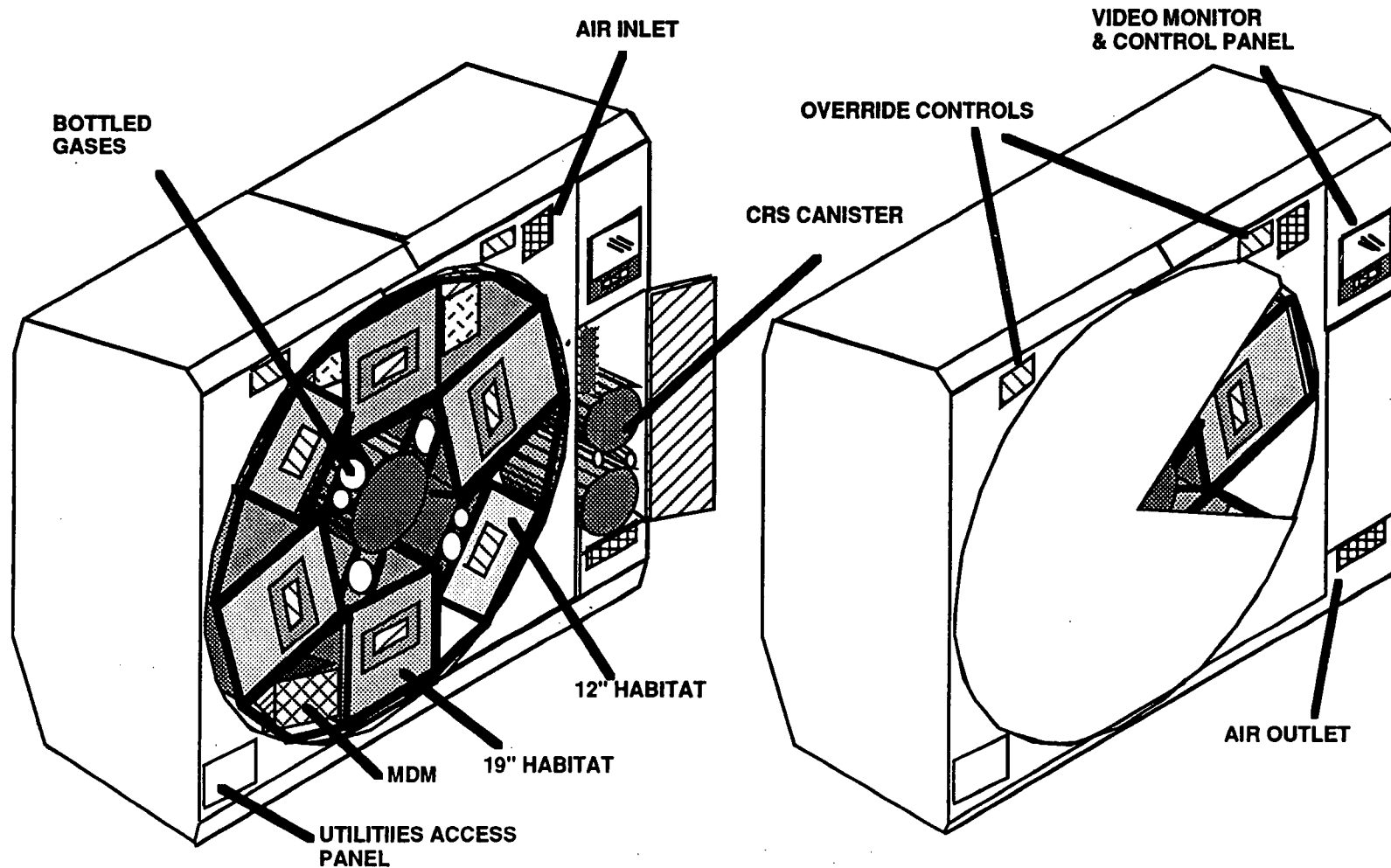
SUMMARY

- System design meets most requirements
- Required technology already demonstrated with exceptions previously noted
- Rack volume is severely constrained to accommodate all necessary systems for support of habitats as specified in requirements
- System requires significant support from Freedom
 - Ultrapure water
 - Gas tank recharging at high pressure (1500 psi)
 - Processing of waste materials and liquids
 - CRS canisters and filters

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 6

Centrifuge System



CENTRIFUGE PRESENTATION OUTLINE

The facing page lists an outline for this chapter of the report.

CENTRIFUGE PRESENTATION OUTLINE

- Primary Requirements
- System Description
- System Characteristics (block diagrams and views)
- System Interfaces
- Technical Issues/Analysis
- System Tradeoffs
- Technology Development
- Requirements Not Met / Concerns
- Summary

PRIMARY REQUIREMENTS

The purpose of the Centrifuge System is to provide a variable gravity environment to be used in conjunction with the Holding System in the performance of life science experiments.

The Centrifuge in this report is designed for the Space Station Freedom. The design must fit within the envelope associated with two standard 74.5" functional racks with curved backs. Ducting, valves and a Contaminant Removal System provide two way bioisolation between Freedom and the specimen in the habitats.

To accommodate the specimens over the 90 day mission, the Centrifuge provides resources which support animal habitats for ≥ 14 days and plant habitats for ≥ 90 days. Also the Centrifuge provides controls to maintain environmental parameters for the habitats.

A standard set of habitat interfaces have been developed for the Facility design as mentioned in Chapter 1. The Centrifuge provides the resources necessary for habitat accommodation through this interface.

PRIMARY REQUIREMENTS

- Support modular habitats for variable gravity experiments with rodents, primates and plants in space (from 0.01g to 2.0g)
- Accommodate ≥ 4 primate or plant habitats or ≥ 6 rodent habitats
- Accommodate mixed habitat types (restrained primates, rodents and plants) simultaneously
- Satisfy Freedom interface requirements
- Constrained to two 74.5" standard double rack envelopes
- Satisfy habitat interface requirements (resources: power,air,food,water,waste recovery)
- Maintain environmental control parameters for each habitat
- Provide bioisolation between habitats and Space Station Freedom
- Provide water for animals ≥ 14 days without resupply
- Provide water and gases for plants ≥ 90 days without resupply

PRIMARY REQUIREMENTS (CONT'D)

The Centrifuge is designed to fit within two standard rack envelopes. To assure mobility through the Space Station Freedom, the Centrifuge must disassemble into sections which fit through Space Station hatches.

To reduce secondary acceleration effects from Coriolis accelerations and gravity gradients, the radial distance between specimens and the center of rotation is to be as large as possible.

Disturbances both from the Centrifuge to the specimens and to Freedom must be limited. This implies the necessity to provide an extraction device able to remove specimen habitats from the rotor without despinning the Centrifuge, the need for a main balancing device to reduce imbalances, and the need to reduce angular momentum, possibly by using a counter rotating wheel which cancels the net angular momentum from the Centrifuge to Freedom.

PRIMARY REQUIREMENTS (CONT'D)

- Must disassemble to pass through the resource node and the U.S. Lab Module ingress/egress hatch.
- Radial distance from the Centrifuge axis of rotation to the specimen location within the habitats shall be maximized
- Disturbances generated by the Centrifuge and transmitted to the S.S. Freedom shall not exceed specified limits
- Capability for decentrifugation and extraction of selected habitats without affecting the centrifugation of other habitats
- Must limit changes in total system angular momentum due to starting and stopping the Centrifuge

SYSTEM DESCRIPTION

The layout on the facing page shows the relative locations of the major components. Most high power systems are located on one side. The fluid and data systems are located together on one side to facilitate replacement of filters, tanks and fluid system components.

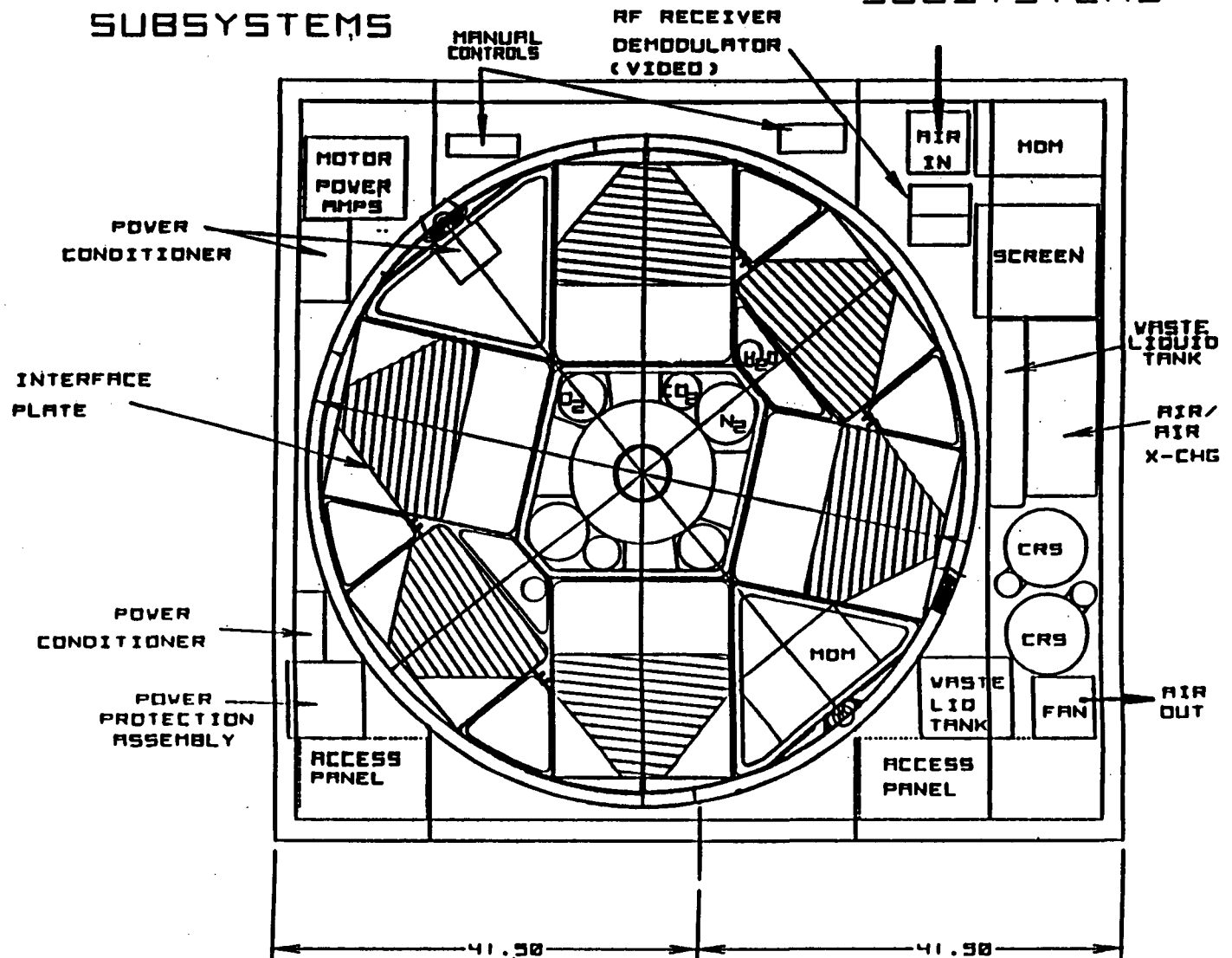
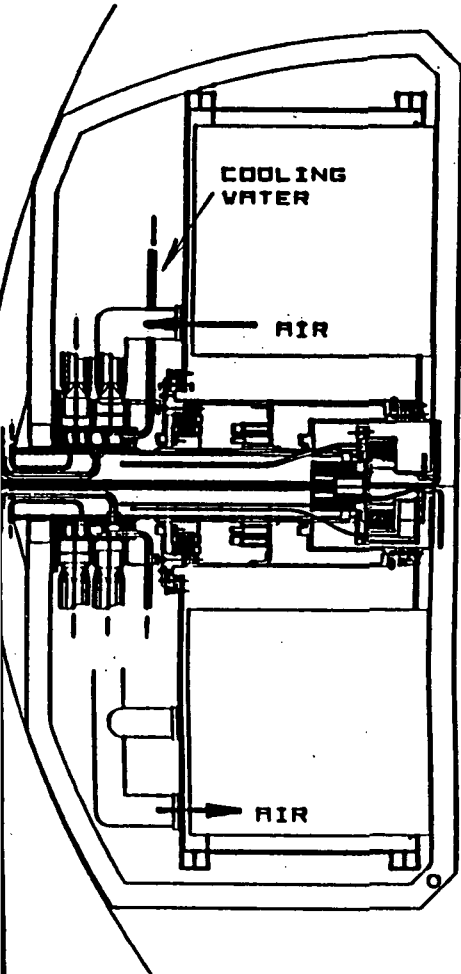
The air inlet and outlet to the Centrifuge are located in opposite corners to maximize the distance between them. The increased distance reduces the potential for CO₂ from the outlet vent to increase the inlet air CO₂ concentrations above the allowable limits. Freedom CO₂ processing systems will remove the CO₂ from the cabin air.

The left hand view depicts a cross section through the Centrifuge. It depicts a potential interference with the upper curvature of the rack structure, which limits the rotor diameter. Some of the fluid lines to the habitats and the rotary transfer joints in the central hub area are shown as well.

CENTRIFUGE LAYOUT

ELECTRICAL SUBSYSTEMS

FLUID SUBSYSTEMS



SYSTEM DESCRIPTION (CONT'D)

Specimen support functions are divided between the habitats and the Centrifuge. The primary function of the Centrifuge is to provide a variable gravity environment for the habitats. The Centrifuge is also the direct interface between Freedom resources and the habitats. Many design aspects of Freedom continue to change. This will change the requirements for the user interfaces to resources. The resource interface requirements in this report are based on the understanding of Freedom as of June 1989.

The thermal control system is based on access to a 4°C water coolant loop supplied by a Freedom water to water heat exchanger, avionics air ports at the top and bottom of the rack, and heat rejection to the cabin air.

The Freedom data management system interfaces with the Centrifuge through a Network Interface Unit. The power supplied by Freedom is 120 Vdc.

An ultrapure water supply meets the requirements for both animal drinking water and plant experiments.

Cabin air has the same composition as air required for animal experiments. A coarse filter and HEPA filter remove foreign debris from the inlet air. A temperature and humidity control system conditions the air to meet requirements for each habitat.

Medical grade N₂, CO₂, and O₂ will be supplied by Freedom through an onboard tank storage facility. Tanks from the Centrifuge will be transported to the storage facility and recharged on a scheduled basis.

Freedom waste management systems will be used to process and store waste products from the Centrifuge. Humidity condensate from the chilled cabin air will be plumbed into a Water Recovery Management System to reclaim useable water. Waste liquids from the waste liquid storage tanks will be plumbed to a Process Materials Management System to reclaim useable products and store waste products for disposal.

SYSTEM DESCRIPTION (CONT'D)

- Used to hold habitats for variable gravity experiments in space. Centrifuge- 0.01 to 2.0g's at a radius of 30.2in.
- Holds 6 small habitats or 4 medium and 2 small habitats
- Conforms to envelope from two Space Station Freedom standard 74.5" racks
- Divides into sections to fit through hatches
- Uses Space Station Freedom resources
 - Thermal control loop
 - Data management system
 - Power
 - Ultrapure water
 - Nitrogen, oxygen, carbon dioxide
 - Process Materials Management System
 - Water Recovery Management System

SYSTEM DESCRIPTION (CONT'D)

Habitat monitoring and control is provided by the Centrifuge control system. The Centrifuge has a connector into which a Freedom Portable Multipurpose Application Console (MPAC) can be plugged. There is also a display monitor and control panel on the front of the Centrifuge from which critical commands can be executed. The Centrifuge is designed to provide resources to the Habitats through a standard interface plate located at the rear of each habitat.

Bioisolation between the crew and specimens is maintained with sealed ducting and a negative pressure, relative to the cabin, of all contaminated areas during normal operation of the Holding System.

Freedom is scheduled to operate for up to 30 years. This implies that the Centrifuge hardware must meet challenging reliability criteria. The hardware must also be easily maintained or replaced. To facilitate maintenance, dual gas supply tanks, waste liquid storage tanks and contaminant removal canisters have been incorporated into the design. This redundancy permits an item to be replaced while the Centrifuge continues to operate. It also provides a backup for the system in the event of a failure. Most of these components are accessible from the front of the rack. Inlet air filters are in the front to allow occasional cleaning as they accumulate loose particles from the cabin air.

SYSTEM DESCRIPTION (CONT'D)

- Provides capability for habitat monitoring and control
- Provides standard resources through interface plate located at rear of habitats
- Two levels of bioisolation
 - Structural containment with sealed, single pass air loop including HEPA filters
 - Negative air pressure throughout Centrifuge ECLS system
- Maintenance
 - Dual tanks for expendables and wastes permit uninterrupted operation during replenishment
 - Easy access provided for units needing routine maintenance
 - Waste tanks serviced from the front
 - CRS serviced from the front

SYSTEM DESCRIPTION (CONT'D)

For flexibility, the Centrifuge can accommodate multiple habitat types simultaneously. This permits operations with a variety of specimens during any mission interval. To accommodate a variety of specimens simultaneously, the Centrifuge must supply resources for plants and animals to every habitat interface. This was accomplished in the design presented.

A mass balancer will be implemented to reduce the disturbances to the Space Station. A description is given later in this chapter.

Controls and procedures will be developed to meet safety requirements. A control panel and display screen are located on the front of the Centrifuge to input commands. Manual backup switches for critical control commands will be provided at the front of the Centrifuge.

SYSTEM DESCRIPTION (CONT'D)

- Accommodates multiple specimen habitat types simultaneously
 - Study based on rats, squirrel monkeys and plants
- Animal habitat support
 - Conditioned inlet air
 - Single pass environmental control system (no recirculation)
- Plant habitat support
 - Expendable gasses supplied by dual tanks
 - Continuous supply of ultrapure water
 - Collect liquid wastes for transfer to liquid waste storage
 - Continuous supply of coolant water
- Reduce disturbance to micro-gravity environment
- Video display screen for control or habitat monitoring
- Separate emergency controls hardwired to front of rack

SYSTEM DESCRIPTION (CONT'D)

The Centrifuge life support system provides the necessary life support resources to the habitats. The life support resource connections are the same at each habitat interface. In this way habitat locations may vary for each mission without reconfiguring the Centrifuge.

The life support system supplies air to the habitats, controls the inlet air temperature and humidity, processes the air before it is exhausted to the cabin, provides liquid storage, and supplies water and gases to the habitats.

LIFE SUPPORT SYSTEM FUNCTIONS

Flow of respiration air, gas, drinking water and temperature control:

- 4700 cc/s (10 cfm) single pass airflow through the ducting at negative pressure (relative to cabin pressure)
- Controlled temperature within allowable humidity range
- Waste air processing prior to exhaust to cabin - CO₂ removal provided by Freedom
- Ultrapure water supply
- Waste liquid storage
- Ultrapure gas supply
- Centrifuge life support system similar to the Holding Unit

SYSTEM DESCRIPTION (CONT'D)

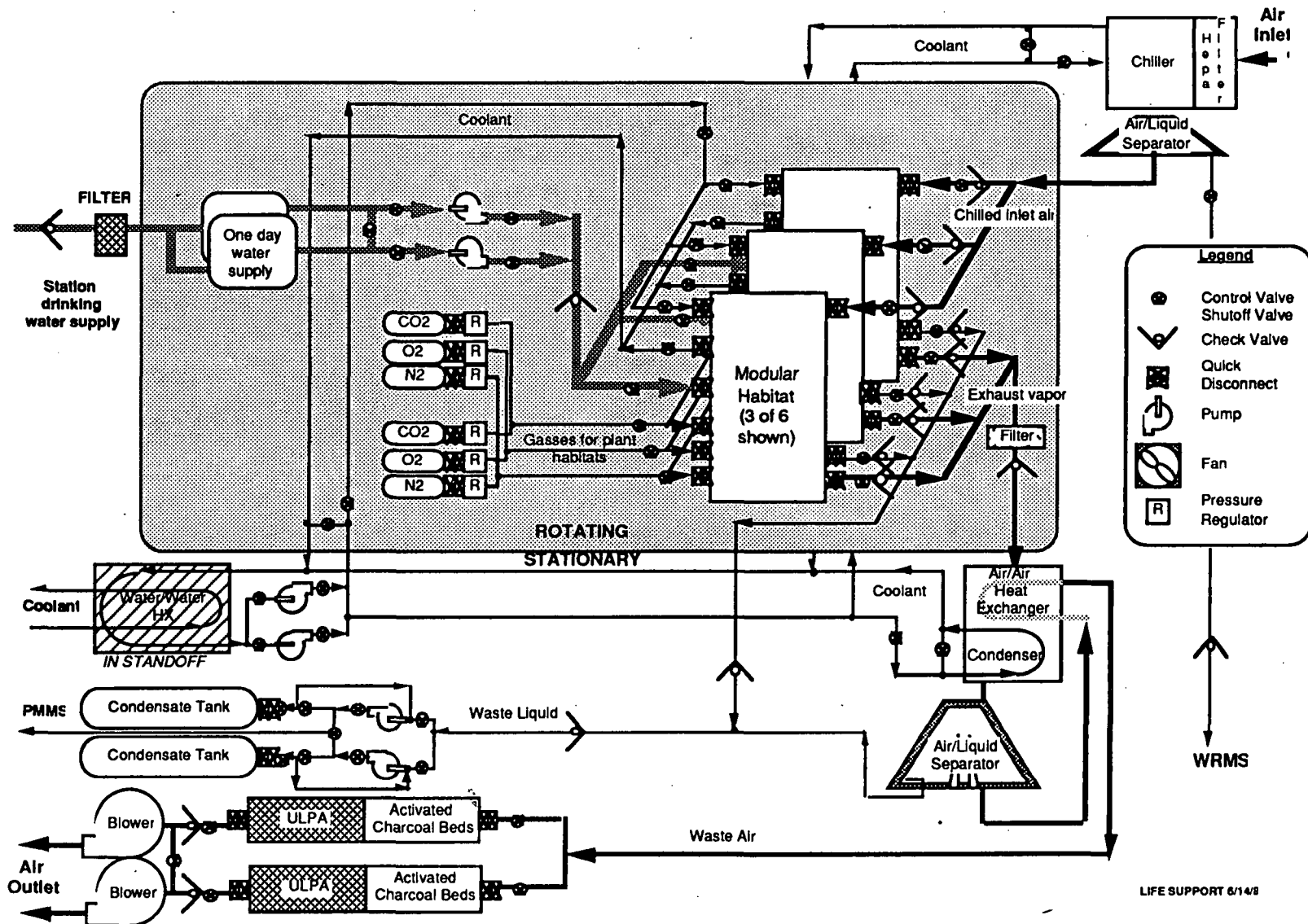
The heavy line in the Life Support Block Diagram indicates the flow of cabin air through the Centrifuge. Cabin air enters the system through a HEPA filter, a heat exchanger and an air-water separator which conditions it to the lowest temperature/humidity level required by the habitats. Control valves at each habitat air inlet control the air flow to the habitats. Check valves located in the ducting at the habitat air inlets and outlets assure one-way flow through the habitats.

Redundant blowers at the air exhaust create negative pressure (with respect to cabin ambient pressure) within the system. Waste air from the habitats passes through a coarse filter, is cooled by the waste air heat exchanger and drawn into the air/liquid separator. Air which exits the separator passes through one of two Contaminant Removal System (CRS) tanks. This redundancy allows replacement of one dirty filter, tank or pump while the experiments are running. The final stage of air conditioning is decontamination through the Contaminant Removal System and HEPA filters. From here the air is blown back into the cabin.

Water and gases are supplied to all habitats as indicated by sources to the left of the habitats. Coolant is distributed to all systems which require liquid cooling. This is supplied as a parallel source; all inlets come from a common line and all coolant outlets are plumbed to a common line.

All of the life support fluids (except gases) pass from the stationary portion of the rack to the rotating portion. Gases required by the Plant Habitats, are placed in tanks on the rotor. This eliminates the need for additional rotary joints, required if the gases were passed through the hub.

LIFE SUPPORT BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

Animals are supplied with filtered cabin air for respiration by inlet ducting (shown earlier). The Holding System utilizes a single pass air flow system, i.e., air is exhausted from the cabin, filtered, passed through the habitats, processed, and then returned to the cabin. The exhaust air from the habitats carries with it the CO₂ build up from the animals at over 10 air changes per hour. A nominal airflow rate of 4700 cubic centimeters per second (10 cfm), which corresponds to a rate of 470 cc/s (1-2 cfm) for each habitat, has been selected to avoid system penalties (power, weight and volume) associated with higher airflow rates. This provides 50-100 air changes per hour for the habitats. The habitats have quick disconnects on the air inlet and outlet that seal upon disconnect.

AIRFLOW

- >10 air changes per hour within habitats
- Single pass air entering the Centrifuge passes through:
 - HEPA inlet filter
 - Heat exchanger to condense vapors and cool the air
 - Phase separator to remove condensate
 - Rotary joint and through the habitats
 - Coarse filter to prevent rotary joint clogging
 - Rotary joint to an air to air heat exchanger to preheat the outlet air
 - Another condenser and phase separator to remove animal respiration products
 - Contaminant Removal System (CRS) to remove contaminants
 - HEPA filter to remove bacteria and viruses
 - Blower to circulate the air into the cabin
- 4700 cc/s (10 cfm) is the nominal design flow through the entire system

SYSTEM DESCRIPTION (CONT'D)

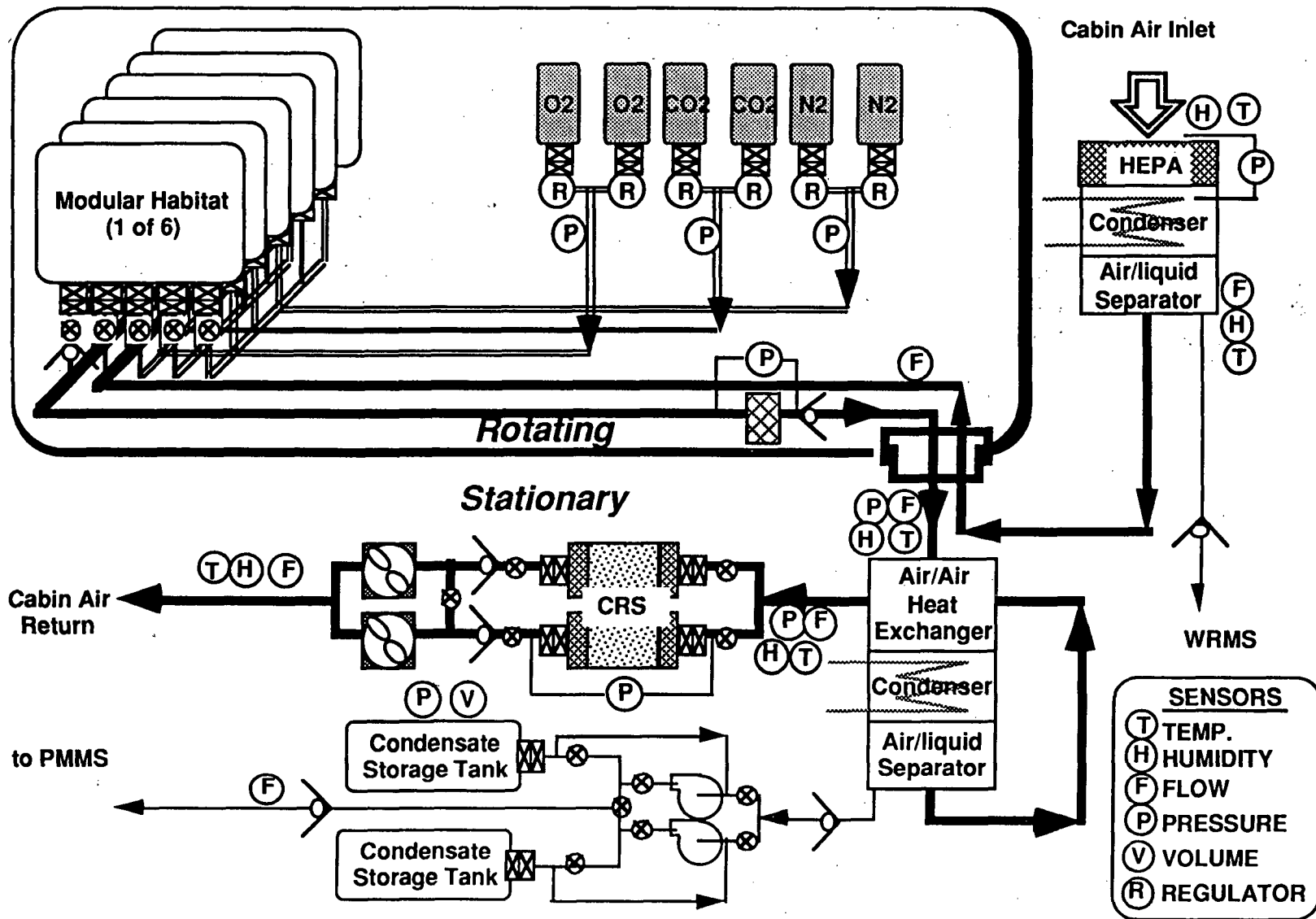
The block diagram on the facing page shows the airflow paths through the Centrifuge. Locations for sensors are included.

The heavy lines correspond to the flow of respiration air through the Centrifuge. As seen to the right, filtered cabin air is used as the inlet air source. This air is preconditioned to meet the inlet conditions for the experiments to be conducted.

Clean air passes through the rotary transfer joint and is routed to each of the habitats. Contaminated air from the habitats passes through the rotary joint, through a heat exchanger and condenser, to a Contaminant Removal System shown on the stationary portion of the Centrifuge.

Condensate from the inlet air and liquid waste from the habitat exhaust is plumbed to the corresponding processing system on Freedom.

AIR FLOW BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The facing page lists estimates for the data rates necessary to operate the Centrifuge System and meet the experiment data collection requirements. The data required for scientific measurement far surpass the data required to operate the hardware alone. This is evident in comparing the engineering data rates with the science data rates. Some Engineering data are required for scientific purpose.

The large variance in data rates for the animals is due to the variance in the type of experiments to be performed. The high data rates come from experiments which require high frequency response to specimen activities, such as muscle electrical impulses. The data rates required to monitor and control environmental parameters are negligible when compared to the science experiment requirements.

CENTRIFUGE DATA RATES

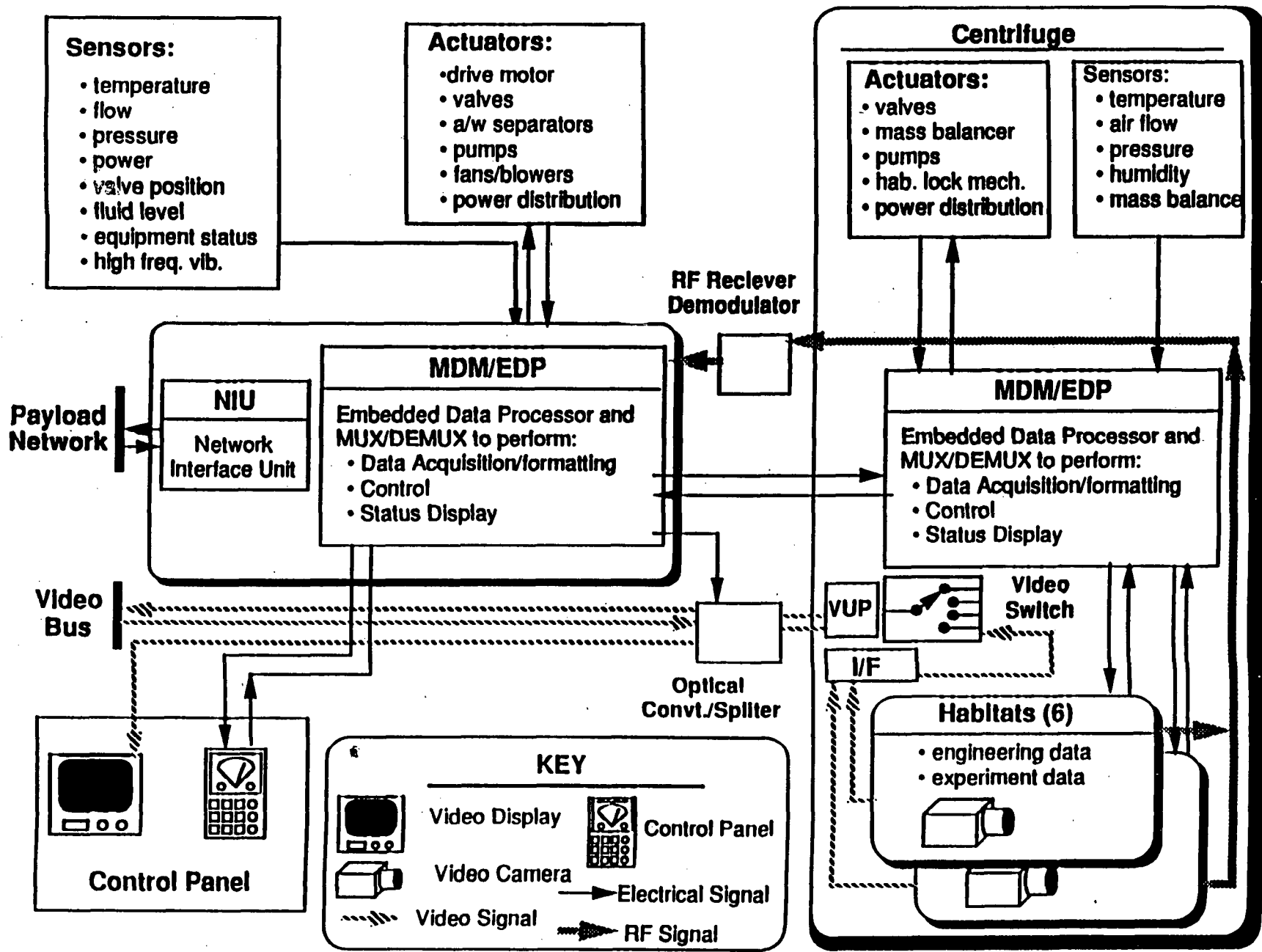
<u>Data Type</u>	<u>Data Rates</u>
Engineering data	80 kbps
Science data	
Rodent Experiments (6 Habitats)	
Nominal	1500 kbps
Maximum	4068 kbps
Primate Experiments (4 Habitats)	
Nominal	1416 kbps
Maximum	4448 kbps
Plant Experiments (4 Habitats)	
Nominal	1.8 kbps
Maximum	5.4 kbps
Maximum System data rates	4149 kbps
Internal Video channels	2 channels/habitat
Video Output to Freedom(after multiplexing)	1 channel

SYSTEM DESCRIPTION (CONT'D)

The central controller for data collection, packaging and transmission is the Freedom supplied Multiplexer/Demultiplexer computer and Embedded Data Processor. Experiment specific cards are inserted into the MDM to perform the required tasks. As shown in the figure the MDM controls all sensors, actuators, switches, and habitats (as required). It also serves as the interface between the payload data network and the Centrifuge.

It should be noted that the EDP (Embedded Data Processor) has been deleted from the Freedom Program subsequent to completion of this study. This feature of the design will have to be modified in future studies.

DATA BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

All power to the Centrifuge will be supplied by the Freedom 120 volt dc power inlet. All racks require power protection assemblies to reduce the risk of overloading the Freedom power system. Redundant assemblies are used to assure protection while maintaining the Centrifuge operation to the maximum extent possible

Electronic subsystem units typically use 28 Vdc power, therefore the baseline system includes a converter to provide power at that voltage level. Should other voltages be required, conversion to the required level(s) will be included in the design. Direct current converters will be located on the stationary portion of the Centrifuge to off load mass from the rotor. It was assumed that all power transferred across the rotary joint would be dc power and the transfer mechanism used is the roll ring being developed by NASA LERC for the Freedom program under contract NAS3-24264.

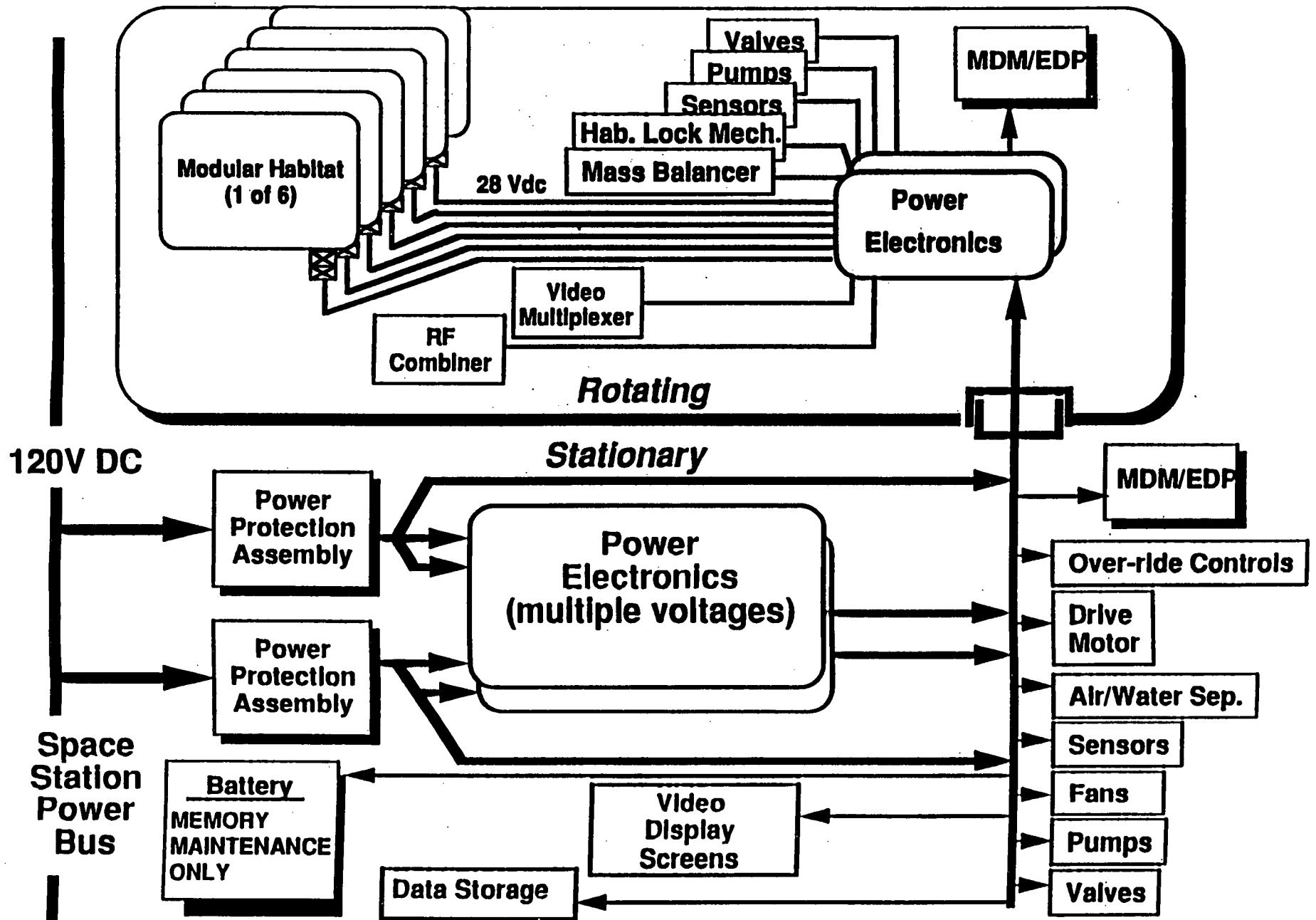
POWER

- Accepts 120Vdc power from Freedom
- Redundant power protection assemblies
- Conditions power down to component requirements (28Vdc, 12Vdc)
- Power could be transferred to rotor at 28Vdc versus 120Vdc (Allows the large conditioners to be on the stationary side)
- DC Power transfer using "Roll Ring" being developed under NAS3-24264
- Battery unit provides back-up power for volatile memory

SYSTEM DESCRIPTION (CONT'D)

Freedom supplies electrical power to users at 120 Vdc. The Centrifuge converts this power supply to 28 Vdc power for habitats, fans, blowers and other mechanisms. After conversion the power is distributed to all electrical components. Power protection assemblies provide circuit breakers and allow Freedom control of the power usage.

POWER BLOCK DIAGRAM

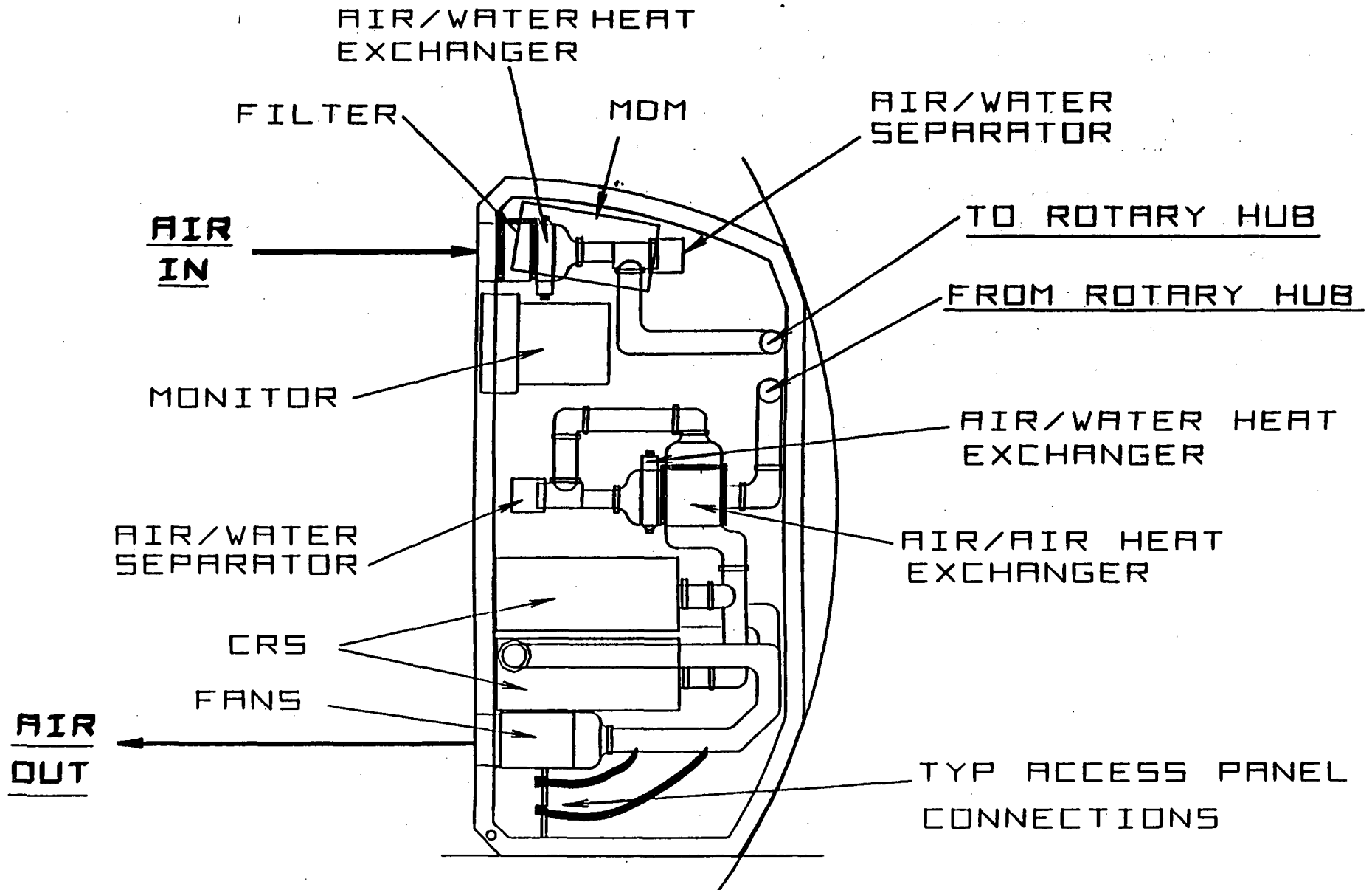


SYSTEM DESCRIPTION (CONT'D)

The facing page depicts a side view of the Centrifuge showing the fluid system components. Note that the air inlet and outlet are located at the top and bottom of the rack respectively. This arrangement increases the distance between the air source and air exhaust for the Centrifuge thus reducing the cross contamination effects prior to air reprocessing by Freedom systems. This layout shows the relative size and complexity of the air system based on preliminary estimates.

Note also that components which may require frequent servicing, such as the CRS canisters, are accessible from the front of the rack.

FLUID SUBSYSTEMS LAYOUT



SYSTEM DESCRIPTION (CONT'D)

The rotary hub is a complex subsystem of paramount importance to successful operation of the Centrifuge. Through it, all resources which are supplied by Freedom are transferred from the stationary portion of the Centrifuge to the rotor. During transfer, the loss of fluid must not violate the bioisolation requirements and the power losses should be a minimum. Also, fluids must be well isolated from each other to avoid cross contamination.

The fluids to be transferred with this design include air in and air out, coolant in and out, distilled water in and waste liquid out. As stated earlier, the gases for the plants will be supplied from tanks on the rotor.

The power transfer device is a roll ring; the RF data will transfer across a slip ring and digital data will transfer across an optical slip ring. In addition to these, there is a contacting slip ring used to transfer up to 35 channels of hardwired data.

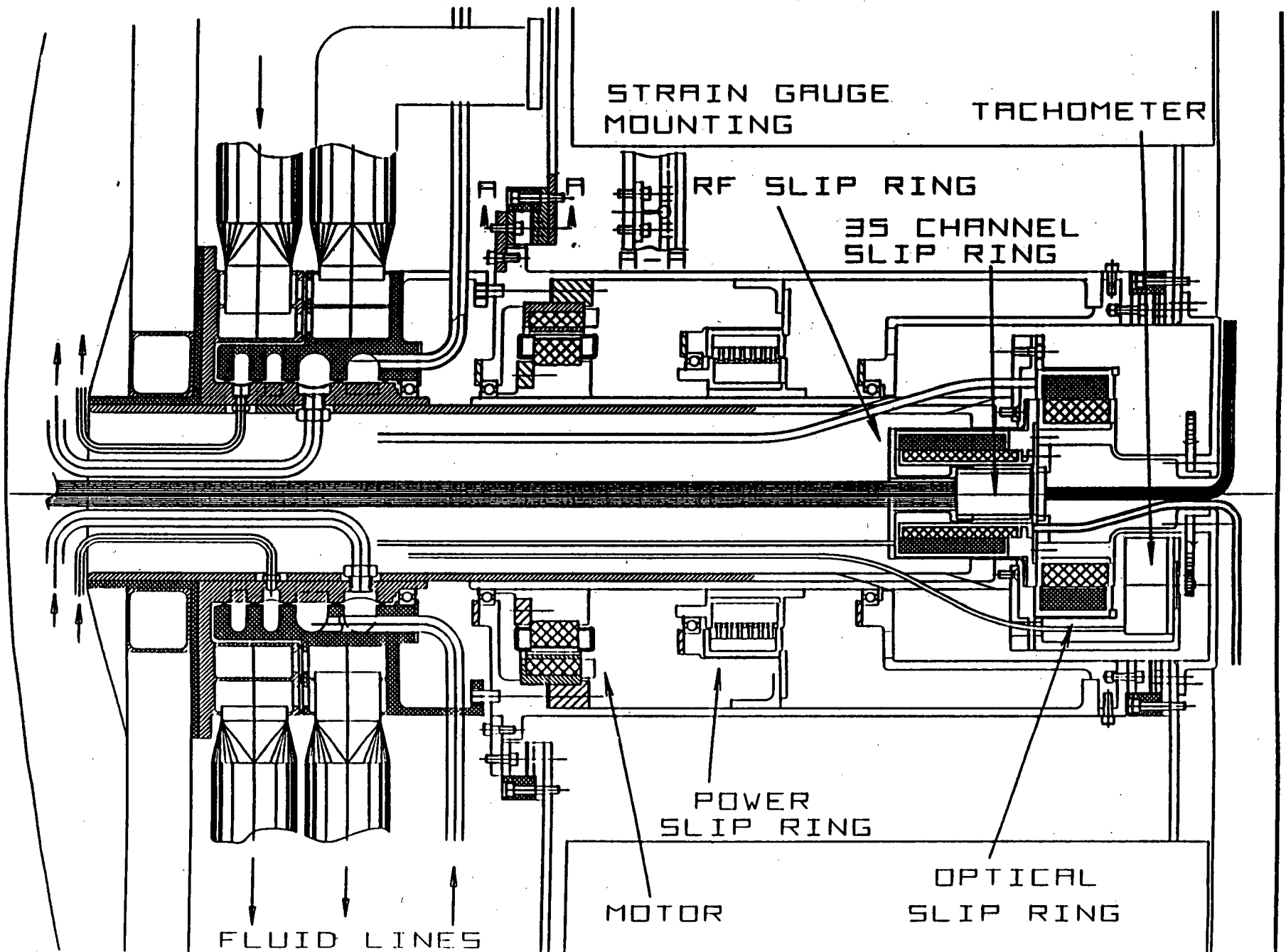
ROTARY HUB

- Two 6 cm (2.5in.) air lines (one in, one out)
- Two 1 cm (0.5in.) cooling water lines (one in, one out)
- Two 6 mm (0.25in.) water lines (distilled, waste liq.)
- Space for a 40ft-lb motor (same torque as mockup)
- Power slip ring (assumed roll ring)
- RF slip ring (TBD)
- Optical slip ring (two channel, existing)
- 35 channel slip ring (commercial, contacting)
- Cantilever shaft mounting for a radial extractor for future Centrifuges
- Mass imbalance detection using multiple beams and strain gauges (alternative is to use accelerometers)

SYSTEM DESCRIPTION (CONT'D)

The facing page shows the layout of the Centrifuge hub as defined for this study. This design utilizes existing or slightly modified standard components for rotary joints and permits disassembly and replacement of most of the components.

ROTARY HUB LAYOUT



CENTRIFUGE CHARACTERISTICS (CONT'D)

The following tables list the mass and volume estimates for the major subsystems within the Centrifuge. The basis for these estimates is listed in the right hand column. 'Freedom' indicates that the value was supplied by Freedom documentation. 'Catalog' indicates that the value was listed in a catalog for a similar component. 'Calculated' indicates that the value was calculated based on worst case usage or scaled from existing hardware. 'Rough Estimate' indicates that little analysis was performed and the value was estimated. The basis for various tanks and container sizes is given in more detail in the Holding System presentation under 'Life Support Consumables'.

No structural analysis was performed for this reference design. To provide a rough estimate of mass for the Centrifuge, aluminum frames and fiberglass skins were used as the basis for estimates of structural mass.

The facing page lists the tallied mass estimates for the major subsystems within the Centrifuge.

CENTRIFUGE MASS ESTIMATES

	Mass kg (lbs)	
Rotor ECLS	103	(226)
Rotor Electronics	30	(65)
Rotor Mechanisms	209	(460)
Habitat Support	25	(54)
Rotor Subtotal	366	(805)
Subtotal w/ Habitats	648	(1425)
Rack ECLS	89	(195)
Rack Electronics	122	(269)
Rack Structure	445	(978)
Rack Subtotal	655	(1442)
Subtotal w/o Habitats	1021	(2247)
Subtotal with 25% Design Contingency	1277	(2809)
Total with Habitats	1559	(3429)

CENTRIFUGE CHARACTERISTICS (CONT'D)

The facing page summarizes mass and volume estimates for the Rotor ECLS, Rotor electronics and Rotor mechanism

CENTRIFUGE MASS/VOLUME ESTIMATE

	Mass		Volume	Basis
	kg	(wt. lbs)	in ³	
Rotor ECLS	103	(226)	3898	
filter	2	(5)	42	Catalog
air plenum	61	(135)	1374	Rough Est
drinking water tanks	4	(8)	181	Calculated
water pumps	5	(12)	128	Calculated
gases tanks	30	(66)	2173	Calculated
Rotor Electronics	30	(65)	2231	
video utility port	0.5	(1)	54	Freedom
power conditioner	2	(5)	400	Calculated
optical slip-ring	3	(7)	339	Exist Hdwr
RF amp/combiner	1	(2)	8	Rough Est
video switch	0.5	(1)	8	Freedom
video I/F & lens	0.5	(1)	24	Exist Hdwr
MDM- mass balancer control	19	(41)	1398	Freedom
wire harness	3	(6)		7-10% elec
Rotor Mechanisms	209	(460)	3162	
bearing assy	9	(20)	226	Rough Est
balancer motors	4	(8)	50	Rough Est
balancer masses	97	(214)	306	Calculate
shroud	27	(60)	995	Rough Est
structure	72	(158)	1584	Rough Est

CENTRIFUGE CHARACTERISTICS (CONT'D)

The facing page summarizes mass and volume estimates for Habitat and support systems, and Rack (or stationary) ECLS components.

CENTRIFUGE MASS/VOLUME ESTIMATE

		Dry Mass		Volume	Basis
		kg	(wt. lbs)	in ³	
Habitats & Support	306		(674)	34717	
plant habs		218	(480)	25840	Calculate
rodent habs		64	(140)	8160	Calculate
interface plates		14	(30)	612	Calculate
slide hardware		5	(12)	30	Rough Est
seating mech. motors		5	(12)	75	Rough Est
Rack ECLS	89		(195)	6430	
filter		3	(6)	108	Catalog
water/air heat exchangers		2	(5)	144	Catalog
air/liq separators		18	(40)	14	Exist Hdwr
air/air heat exchanger		3	(7)	216	Rough Est
CRS canisters		25	(54)	2011	Calculated
blowers		2	(4)	288	Calculated
condensate tanks		14	(30)	2889	Calculated
pumps		11	(24)	256	Exist Hdwr
water/water heat exchanger		11	(25)	504	Freedom

CENTRIFUGE CHARACTERISTICS (CONT'D)

The facing page provides the mass and volume estimates for the Rack (or stationary) electronics, the Rack structure and totals for the Centrifuge. The "Percent of Allocation" shows the total Centrifuge mass relative to nominal rack structural capability without secondary structural support. With rack capabilities upgraded to the maximum allowable values the Centrifuge mass (including a 25% contingency) is estimated to be at 90% of total capability.

The percent volume is based on 1 cubic meter of rack volume available for users in a standard rack. The Centrifuge is estimated to have a greater volume as it uses custom racks.

CENTRIFUGE MASS/VOLUME ESTIMATE

		Dry kg	Mass (wt. lbs)	Volume in ³	Basis
Rack Electronics	122		(269)	9255	
				816	Freedom
RF receiver/demod		29.5	(65)	648	Calculated
MDM		18.6	(41)	1398	Freedom
power conditioner		10.5	(23)	1830	Calculated
motor power amps		29.5	(65)	1440	Rough Est
video screen		15.9	(35)	1848	Rough Est
fire sensors		0.5	(1)	506	Rough Est
slip rings		6.8	(15)	770	Rough Est
wiring		10.9	(24)		7-10% total elect
Rack Structure	444		(978)	13555	
frames		40	(89)	888	Rough Est
skin		381	(839)	11988	Rough Est
motor		15.9	(35)	452	Catalog
tachometer		6.8	(15)	226	Catalog
Subtotal w/o habitats	1021		(2247)	0.64 m ³ (23 ft ³)	
Subtotal with 25% design contingency	1277		(2809)	0.8 m ³	
Percent of allocation (% of 800 kg launch mass and % of 2 m ³)		158 %		40 %	
Percent allocation with habitats				68 %	no habitat volume contingency

CENTRIFUGE CHARACTERISTICS (CONT'D)

Power usage was estimated for the major components of the Centrifuge. Average power estimates are based on full operation of the Centrifuge; the redundant components are not powered. The electronics are assumed to be powered, which may be a conservative estimate. For example, most experiments would not require power to all systems simultaneously. The power conditioners were assumed to have 15% losses in power conversion.

Heat dissipation is through either the coolant loop, avionics air or cabin air. Most of the Centrifuge heat load is transferred to the water coolant loop which is the most efficient means of heat rejection. Components which cannot reject heat to the water loop will dissipate heat through the avionics air system. Exhaust air will dissipate some heat to the cabin.

CENTRIFUGE POWER ESTIMATES

	Power (watts) Ave/Peak	Heat Disp	Basis
Liquid Separators [2]	168	coolant	Exist
Blowers [2]	150	cabin/av air	Cat
Pumps [6]	84	coolant	Exist
MDM Computer[2]	168	coolant	Freedom
RF Receiver demodulators (24)	72	coolant	Calc
Power conditioner	219	coolant	Calc
Motor power amp	240/512	coolant	Rough est
Power protection assembly	44	coolant	Freedom
Video	160	coolant	Exist
Miscellaneous	139/235	avionics air	Calc
Subtotal without habitats	1444/1812		
Habitats (4 plant & 2 rodent habitats, nominal use)	826/1370	coolant/ cabin air	
Total power with Habitats	2270/3182		
Total with 25% Design Contingency	2838/3978		

CENTRIFUGE CHARACTERISTICS (CONT'D)

Most of the Facility thermal dissipation and transport will use a water coolant loop. Centrifuge connection to the loop is through a water to water heat exchanger located in the lower portion of the rack. One side of this heat exchanger is connected to the Freedom 4°C coolant loop. The other side of the heat exchanger provides a closed coolant loop within the Centrifuge. The estimated temperature at the habitats is 10°C. The coolant is distributed to coldplates on all the electronic components which require liquid cooling. The coolant plumbing in the Centrifuge is parallel (one common inlet and one common outlet) to assure that all habitats have access to the minimum temperature heat sink.

Avionics air will be used to cool areas inaccessible by liquid coolant. The Avionics air input to the rack is through a diffuser in the top of the rack. Avionics air exhausts the rack through a connection at the bottom of the rack. The design of the Centrifuge permits air passage through the areas which require additional heat removal.

Electronic components within the habitats will require air cooling. To eliminate the complications in plumbing avionics air to the habitats, cabin air will be drawn in through the front of the habitats and used to cool the habitat electronics*. This air is circulated through the habitat electronics compartment and exits into the cabin. This cabin air will not mix with the habitat air used for life support. The areas within the habitat which require separate air types remain isolated.

*Recent information from the Freedom Program indicates that severe constraints have been placed on cabin air heat loads. Therefore this feature of the design will have to be modified.

CENTRIFUGE THERMAL SYSTEM

- Coolant loop uses water/water heat exchanger supplied by Freedom
- Interfaces with Freedom 4° C coolant loop (provides ~10°C water in Centrifuge)
- Centrifuge coolant circulates through :
 - Air/water heat exchangers (inlet air chiller and condenser)
 - Water jackets for liquid separators
 - Habitats
 - Coldplates attached to MDM computer, power conditioners, power amps, video monitor, RF rec/demod assembly
- Avionics air circulates through the rack to provide supplemental cooling
- Some heat to cabin air through Centrifuge ECLS air stream
- Projected heat outputs for Centrifuge:
 - 81 watts to cabin air plus 453 watts from habitats
 - 280 watts to avionics air
 - 1444 watts to coolant loop plus 580 watts from habitats and TBD from inlet air chiller

SYSTEM INTERFACES

The habitat support functions have been divided between the habitats and the Centrifuge. The Centrifuge has a standard interface plate from which habitats receive resources. Habitats connect only to resources necessary to support the specimen type within the habitat.

The Centrifuge provides a continuous water supply from Freedom to the habitats with a 24 hr reserve tank as a back up. The water supply meets both science requirements for the specimen drinking or hydration source and Freedom requirements for back contamination. Expelled waste water from the habitats is collected in waste water tanks for storage on the Centrifuge before dumping to a Freedom waste management system.

Animal air quality requirements are satisfied by filtering and conditioning cabin air. Humidity and temperature control are provided by the habitats and the Centrifuge.

Plant habitats require medical grade CO₂, O₂ and N₂. The Centrifuge regulates the gas provided through dual tanks pressurized to 100 atmospheres (1500 psi) to meet the habitat requirements.

Freedom electrical power is supplied to Centrifuge components through a power protection assembly and power conditioner. The power conditioner will convert the incoming Freedom electrical power to 28 V for the habitats. Digital, video, and RF signals from the habitats are processed by Centrifuge subsystems to meet Freedom data network requirements.

SYSTEM HABITAT INTERFACES

CENTRIFUGE TO HABITATS

- Ultrapure water continuously.
- Cooling water at an inlet temperature of 10° C (4° C + allowance for heat exchanger inefficiencies)
- Filtered air from the cabin between 15 and 35° C
- 99.997% pure CO₂ at TBD psi
- 99.997% pure O₂ at TBD psi
- 99.997% pure N₂ at TBD psi
- Electronics and data connection from the habitats to Freedom data network
- Power supplied at 28Vdc
- Waste water line

SYSTEM INTERFACES (CONT'D)

The facing page provides a list of the resources required from Freedom by the Centrifuge.

SYSTEM FREEDOM INTERFACES

SPACE STATION FREEDOM TO CENTRIFUGE

- Power (currently 120 Vdc)
- Data (video, payload network, local data bus)
- 4° C coolant loop
- Avionics air loop
- Fire detection/suppression (req. Freedom definition)
- Cabin air
- Water Reclamation Management System
- Process Materials Management System (for liquid waste processing)
- Ultrapure water
- Gases
 - Nitrogen (recharge tanks at Freedom tank farm)
 - Oxygen (recharge tanks at Freedom tank farm)
 - Carbon Dioxide (recharge tanks at Freedom tank farm)
- Requires non-standard Freedom utilities interface (split between two racks)

TRADEOFFS

A number of system level tradeoffs were made for the Centrifuge, some of which were common to the Holding System as discussed in chapter 5. Reducing power and volume were given priority in the tradeoffs.

Power and volume constraints affect decisions for air temperature and humidity control and cooling system types. Tradeoffs for these systems will be revisited by the contracted Phase B studies to find possible advantages in alternate concepts.

The current choices are highlighted in each tradeoff and a brief rationale is provided.

The tradeoff results are presented in terms of advantages (+) and disadvantages (-). The '+' and '-' symbols are qualitative and not to be tallied to determine the quantitative merits of each option.

SYSTEM TRADEOFFS

- Number of Habitats on Rotor
- Division for Transport
- Mass Balancer
- Extractor

TRADEOFFS (CONT'D)

The facing table records the key points relative to configuration of habitats on the rotor. Illustrations of some mounting locations are depicted on subsequent pages.

HABITATS ON ROTOR

Number of Habitats on Rotor

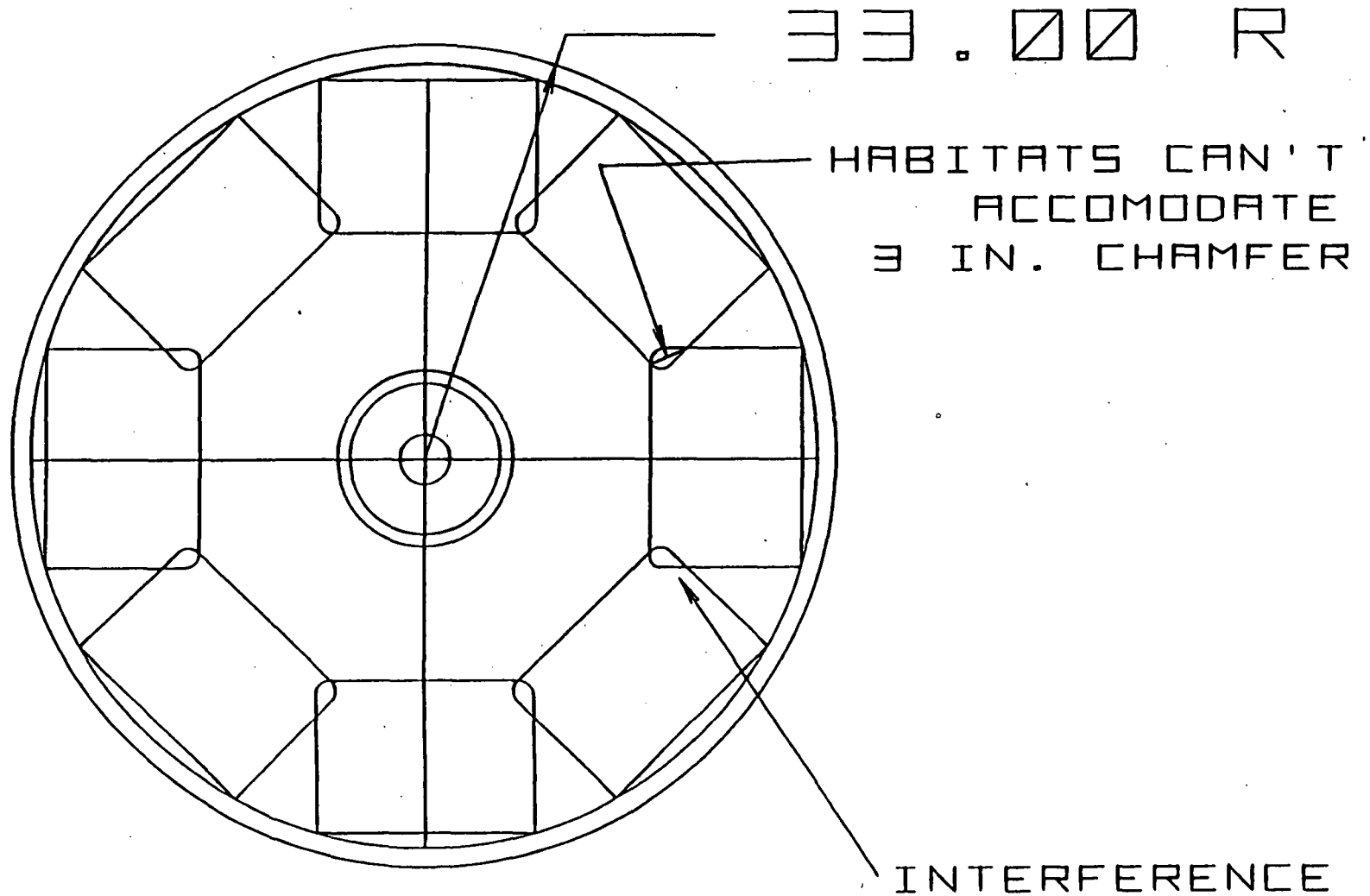
8 Small Habitats	4 Medium and 2 Small
<ul style="list-style-type: none">+ Larger number of specimens- Doesn't accommodate all specimen types- Insufficient volume	<ul style="list-style-type: none">- Low specimen count+ Accommodates all specimen types+ Fits within the envelope

Current Choice: 4 medium and 2 small: all science communities can use Centrifuge; provides largest quantity of specimens in the volume available.

TRADEOFFS (CONT'D)

The facing page illustrates an arrangement of 8 rodent habitats on the rotor. Note the interference of the corners of the habitats. Removing this interference required an increase in the rotor diameter, chamfering of the habitats or another geometric configuration. As stated in the preceding tradeoff, another configuration was selected for the baseline design.

8 SMALL HABITATS



8 SMALL HABITATS
WILL NOT FIT

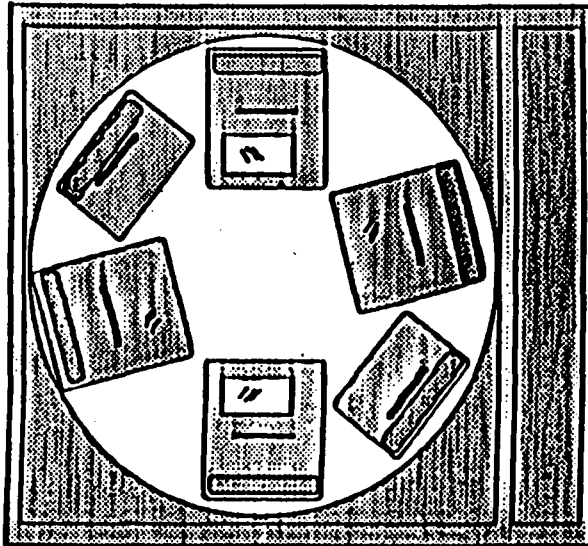
TRADEOFFS (CONT'D)

The facing page depicts a number of geometric configurations for accommodating small and medium habitats. These views are intended to aid the reader in following the logic used in evaluating the tradeoffs associated with habitat arrangement.

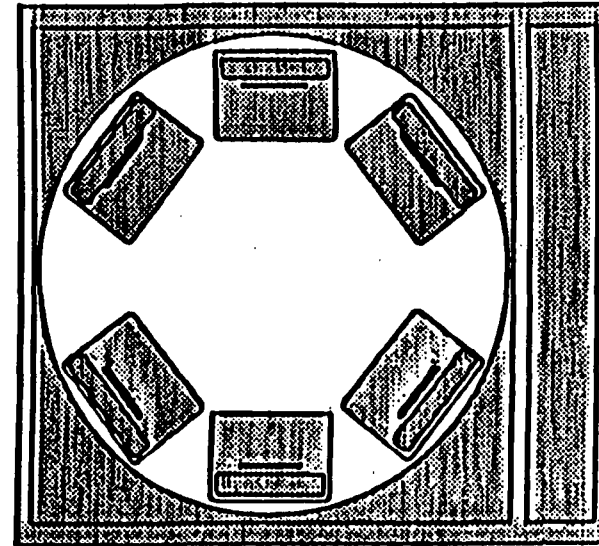
4 MEDIUM AND 2 SMALL

2 Rodent Habitats

**4 restrained
squirrel monkey
or small plant
habitats**

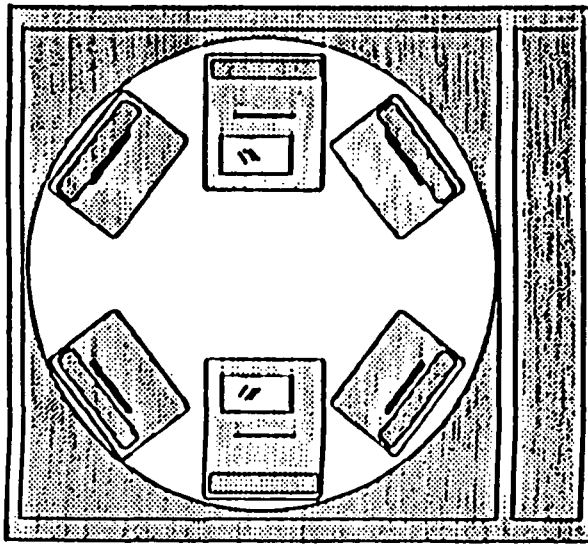


6 Rodent Habitats



4 Rodent Habitats

**2 restrained
squirrel monkey
or small plant
habitats**



TRADEOFFS (CONT'D)

The Centrifuge must be capable of being transported to and from orbit in a logistics module and installed and removed from its Freedom location on-orbit. This requires that it be capable of disassembly into pieces which will fit through a standard Freedom hatch (approximately 50 inches square). The tradeoff discussed here addresses the best way of packaging and dividing a Centrifuge designed to fit within two standard rack spaces while meeting the on-orbit assembly/disassembly constraints.

The first disassembly option locates the rotor in the center of the allocated volume. Dividing the Centrifuge into two double racks places the parting line through the center of the rotary hub. Assembling the many connections and bearings in the hub area for this configuration is not viable. Therefore, other options were considered. These options are tabulated on the facing page.

The Rotor Center/Center option divides the Centrifuge into a central double rack and single rack units on either side. A drawback to this configuration is the lack of large non-rotating volume in which to package the large ECLS components.

The Rotor Left/Half Split locates the rotor to one side of the double rack volume and divides the Centrifuge Unit into two double rack width sections. A drawback to this configuration is a split which divides too much of the tightly packaged hub area.

The Rotor Left/Center is the preferred choice. It locates the rotor to one side of the Centrifuge in a section as wide as a double rack. Two unequal side sections are used to house Centrifuge subsystems. The two remaining ends could be launched as a double rack unit. This provides a large volume in which the ECLS components are located and reduces assembly of structural, air and power connections on the rotor. Pressurized gas lines would not require on orbit assembly, since they only lead to medium size habitat locations contained within the central section.

CENTRIFUGE TRADEOFF

Division for Transport

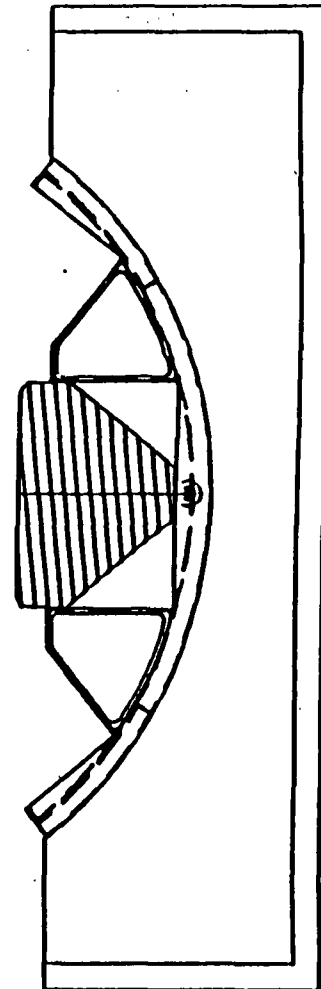
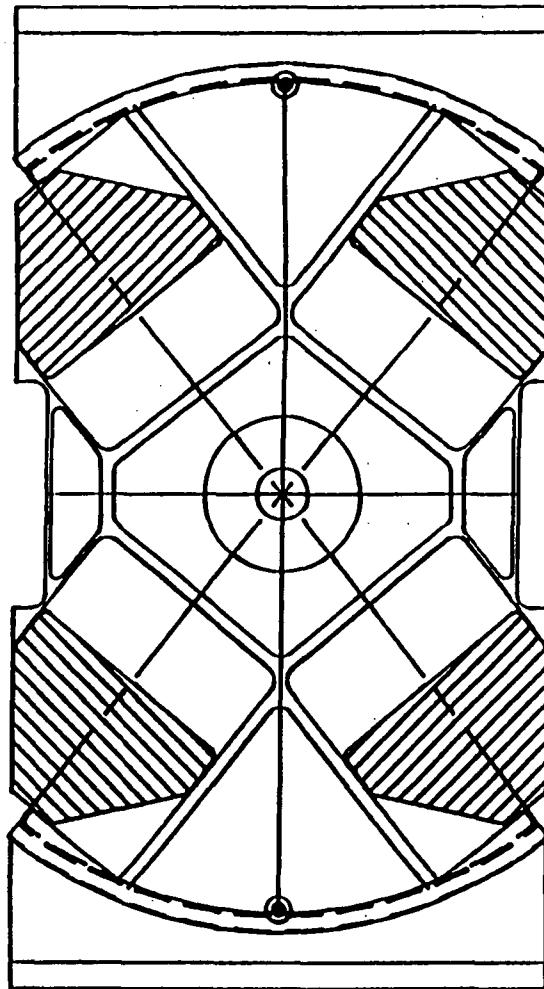
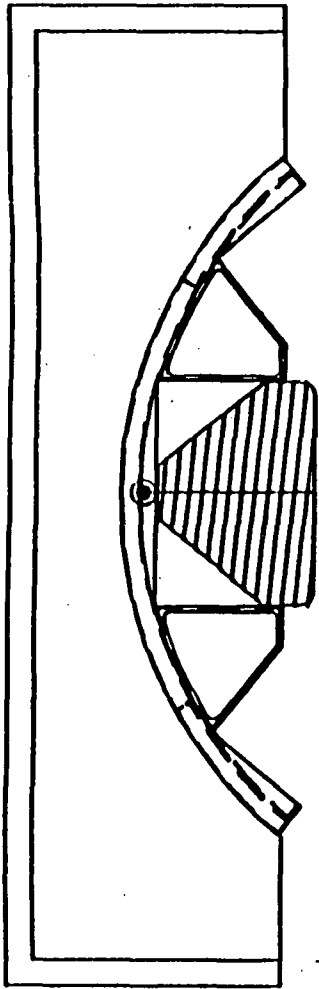
Rotor Center/Center	Rotor Left/Half	Rotor Left/Center
<ul style="list-style-type: none"> + Maintains hub area + Divides as one double rack and two single - Leaves two additional rotor pieces - Leaves no large volume for ECLS - May need extra rack attach points if disassembled for logistics carrier + No large unsupported structure if disassembled for logistics carrier 	<ul style="list-style-type: none"> - Divides hub area + Divides as two double rack size pieces - Leaves one large additional rotor piece + Leaves large volume for ECLS + May not need extra rack attach points if disassembled for logistics carrier - Large unsupported structure if disassembled for logistics carrier 	<ul style="list-style-type: none"> + Maintains hub area + Divides as one double rack and two single - Leaves two additional rotor pieces + Leaves large volume for ECLS - May need extra rack attach points if disassembled for logistics carrier + No large unsupported structure if disassembled for logistics carrier

Current Choice: The Rotor Left/Center provides a large volume for life support systems and has the least structural assembly required in the critical hub area.

TRADEOFFS (CONT'D)

The facing page depicts a layout of the Centrifuge structure divided into a center section and two side sections of equal size. The advantages and disadvantages to this disassembly configuration were provided in the preceding tradeoff table..

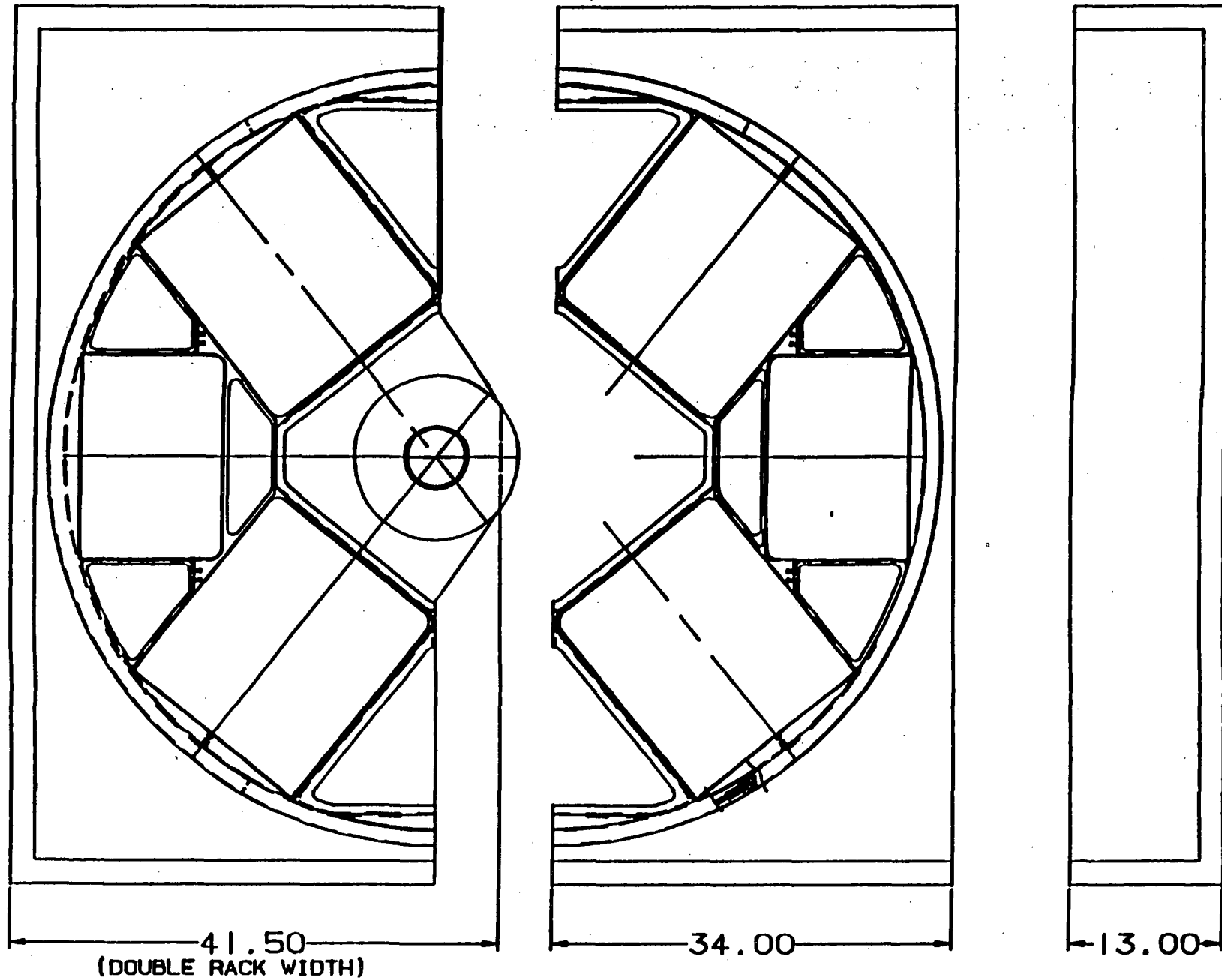
ROTOR CENTER/CENTER



TRADEOFFS (CONT'D)

The facing page depicts a layout of the Centrifuge structure divided into two sections, one of which contains the hub. There is some hub interference as shown by the dashed line. In order for the left half of the Centrifuge to fit into a standard rack, a portion of the hub must be sliced away. The advantages and disadvantages to this disassembly configuration were provided in the preceding tradeoff table.

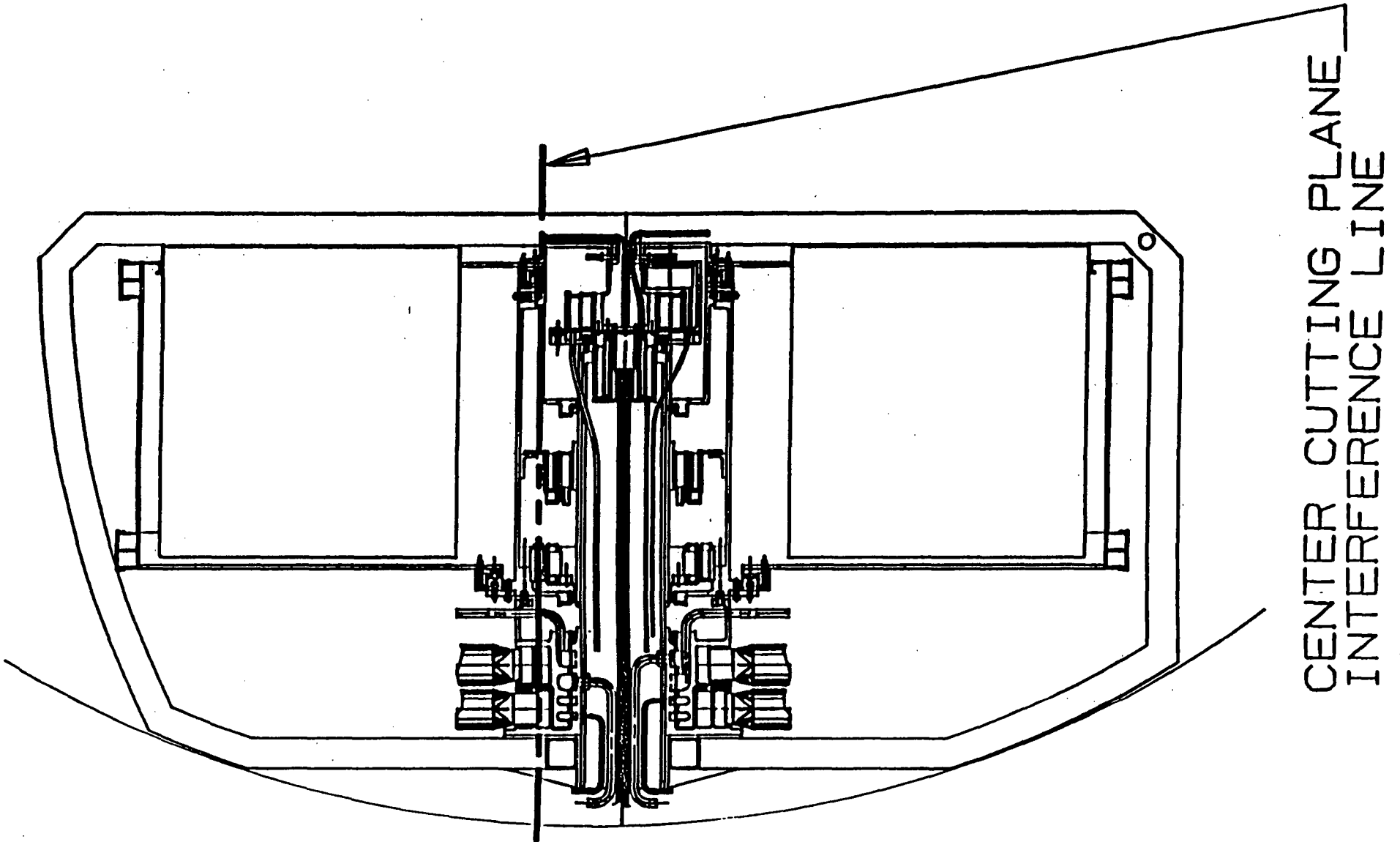
ROTOR LEFT/HALF



TRADEOFFS (CONT'D)

The facing page depicts a side view of the Centrifuge rotor structure. The hub interference line created by the standard rack envelope is shown. The advantages and disadvantages to this disassembly configuration were provided in the preceding tradeoff table.

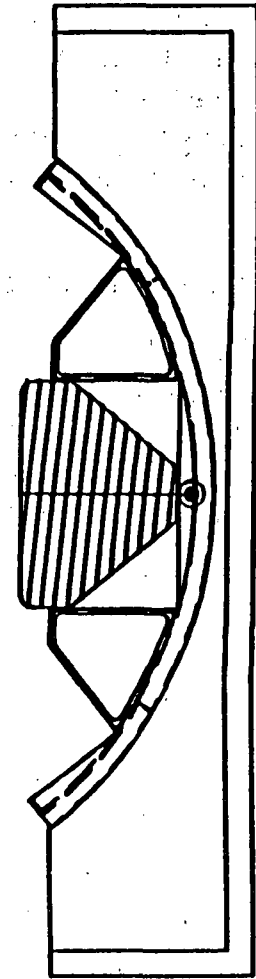
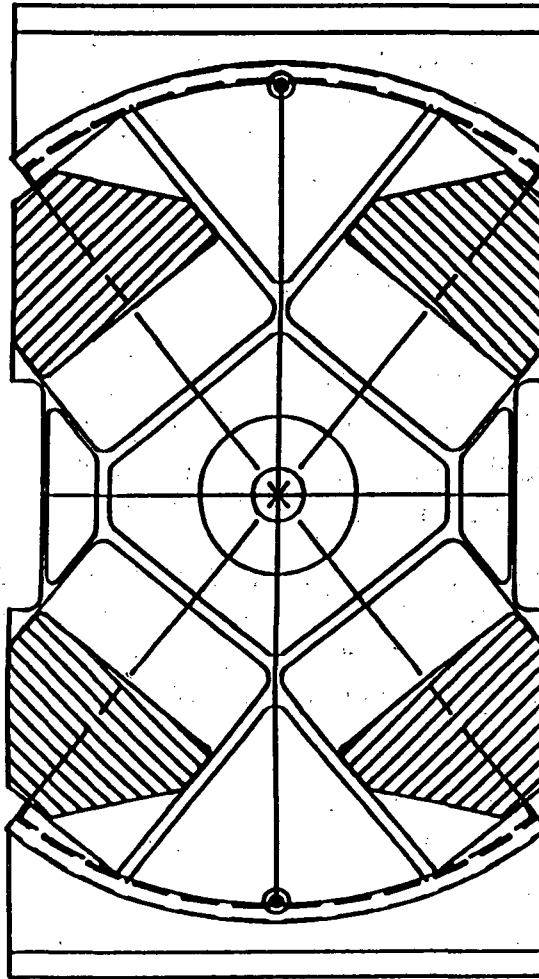
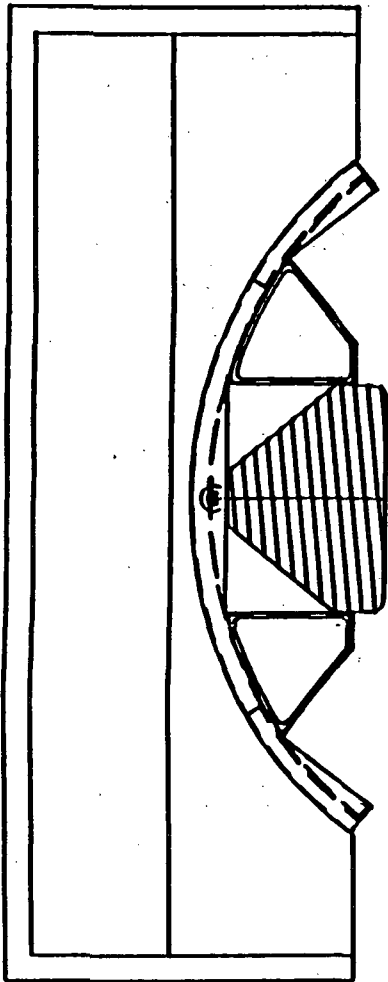
ROTOR LEFT/HALF



TRADEOFFS (CONT'D)

The facing page depicts a layout of the Centrifuge structure divided into three sections, one of which contains the rotor. This configuration differs from the first configuration depicted in that the rotor is not placed directly in the center of the Centrifuge double rack structure, but is located to the left. The two end sections are not symmetrical. The advantages and disadvantages to this disassembly configuration were provided in the preceding tradeoff table. This was the configuration selected as a baseline for this study.

ROTOR LEFT/CENTER



TRADEOFFS (CONT'D)

The Division for Transport tradeoff led to geometric constraints in the area available for standard interface plates for the habitats. The smallest habitat limited the interface plate area. The reference design is approximately 30 cm high by 43 cm wide (12 in. x 17 in.), whereas the necessary area for the connections is considerably less. An interface plate shaped like half an octagon provides area sufficient for all connections without violating the desired central section volume envelope for packaging during launch.

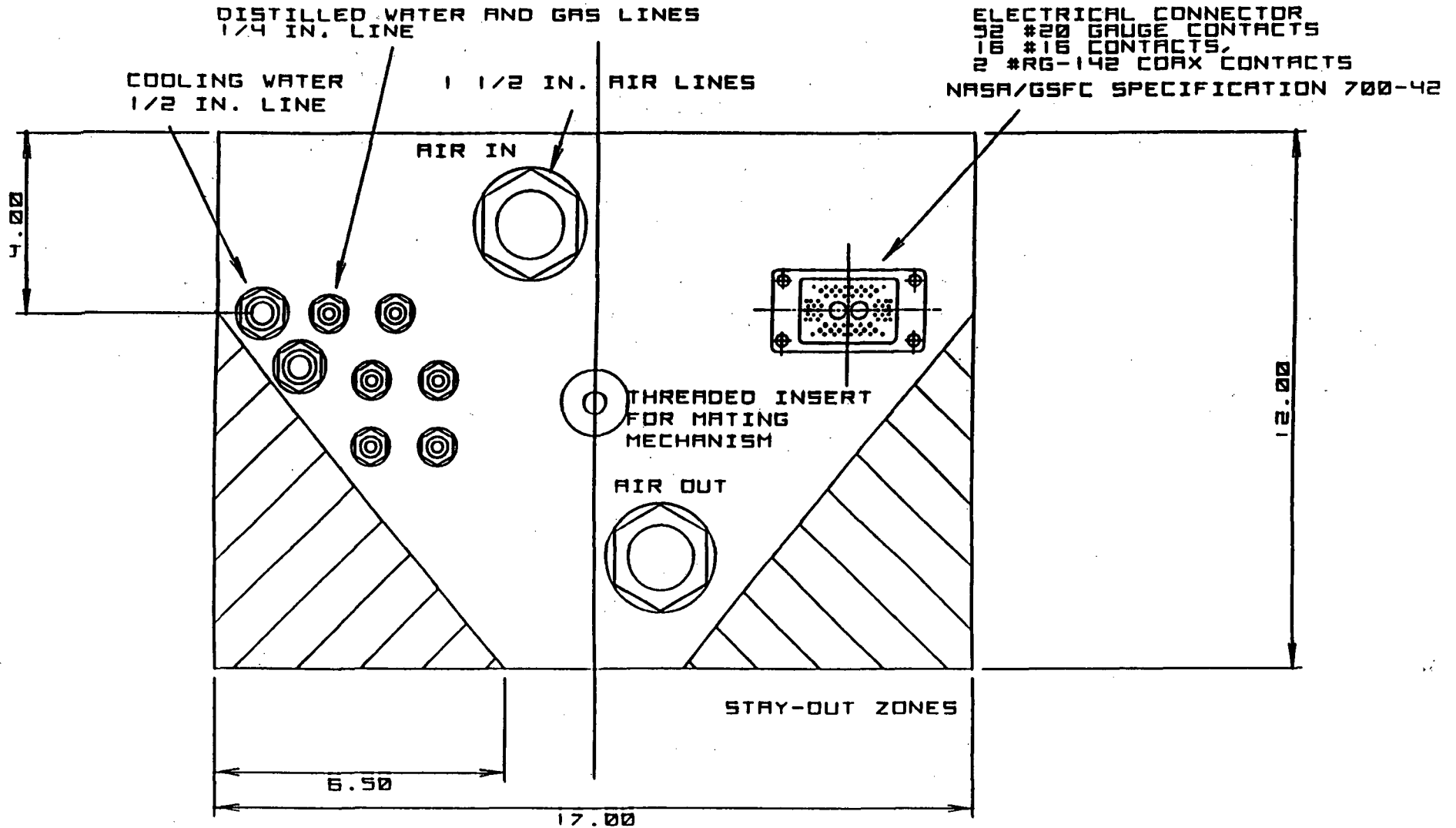
Dimensions of flight qualified connectors were used to verify that existing hardware could fit within the area allocated for the interface plates. The drawing on the facing page is to scale.

The fluid couplings were chosen from a product line more standard than the RAHF water disconnect and meet high quality MIL-SPEC requirements. The probe style connections have shut offs and are designed to be mounted and held together in groups by external structure. A 6mm (0.25 in.) line was the smallest connector used; volume constraints did not require smaller couplers (Reference ARP 1709 and MIL-C-25427).

The selected electrical connector is flight qualified for use on the space shuttle. It is typically used as a satellite umbilical connector or rack and panel connector held together by structure. The reference size provides enough contacts to accommodate all habitat requirements. A smaller size may be considered as habitat requirements are refined.

The 4 cm (1.5 in.) diameter air connections need development. The allotted volume is conservative based on catalog data. The depth of connector penetration into the habitat is of concern; commercial disconnects of this diameter penetrate too far.

STANDARD HABITAT INTERFACE PLATE



INTERFACE PLATE, HOLDING SYSTEM SIDE
HABITAT INTERFACE PLATE MIRROR IMAGE

TRADEOFFS (CONT'D)

The Centrifuge System must be balanced to meet Freedom requirements to provide an undisturbed microgravity environment for the user community. Therefore a dynamic mass balance system is included in the design to limit disturbances at the Centrifuge operating frequency. The Centrifuge rotor will be statically and dynamically balanced very accurately before launch. The mass balancer should be designed to correct for differences in mass and center of gravity between habitats, changes due to water and food consumption, specimen counts, growth rates and slow animal movements.

In order to limit disturbances from the Centrifuge to Freedom due to other features of the design, both active and passive damping systems were considered. However, active systems appear to be eliminated due to volume constraints. This study did not define a specific approach to damping

The facing page lists balancer concepts considered and the tradeoffs associated with selecting one of these approaches for the Centrifuge

Damping systems will attenuate the transmitted vibration at the cost of lowering the frequency of the transmitted force. Active vibration isolation systems are available but cannot be used because of packaging constraints.

MASS BALANCER TRADEOFF

Mass Balancer

Disk	Linear	Radial
+ Large mass	- Small mass	+ Large mass
- Sweeps through large, usable volume	- Sweeps through large, usable volume	+ Sweeps through small, usable volume
- Slow response	+ Fast response	- Slow response

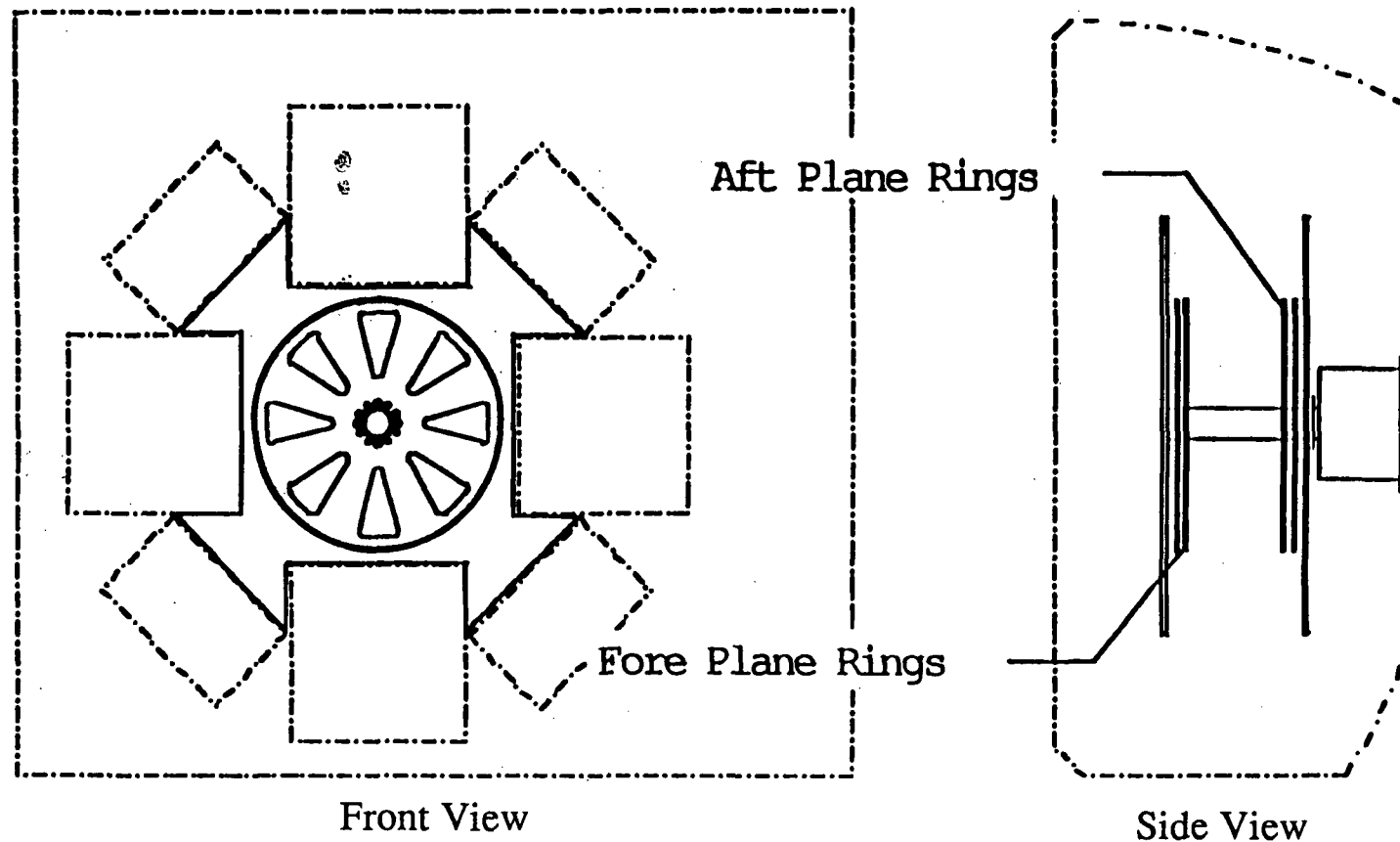
Current Choice: The Radial configuration balances large mass imbalances at low frequency in three axes, with little volume penalty. This and a high frequency, low mass, active vibration isolation system should meet the requirements.

TRADEOFFS (CONT'D)

The disk balancer concepts use two or more disks fabricated such that the mass of each disk is distributed about the axis of rotation non-symmetrically. To counter mass imbalances, the disks are rotated to place the massive end of the disk opposite the mass imbalance. A sketch of this concept is shown on the facing page.

DISK BALANCER

LOCATION OF RING MASS BALANCE CONCEPT

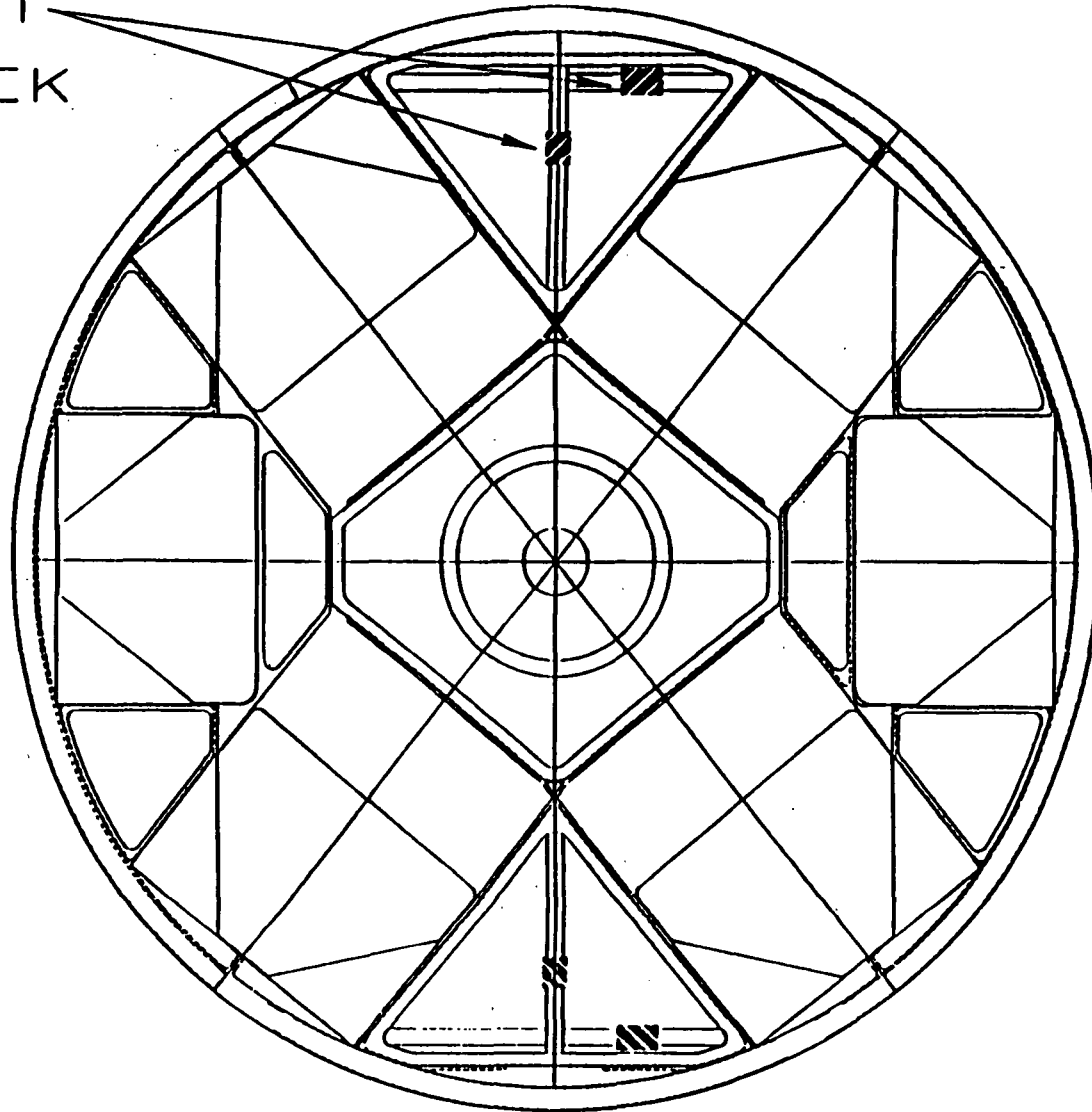


TRADEOFFS (CONT'D)

The linear mass balancer uses masses moved linearly (attached to a threaded rod or linear motor) to counter mass imbalances. The masses are indexed to a moment arm location which will balance the total rotor mass about the center of rotation. A second set of these mechanisms would be required for three axis balance. A front view of this device is shown on the facing page.

LINEAR BALANCER

BALANCE WEIGHT
ON LINEAR TRACK



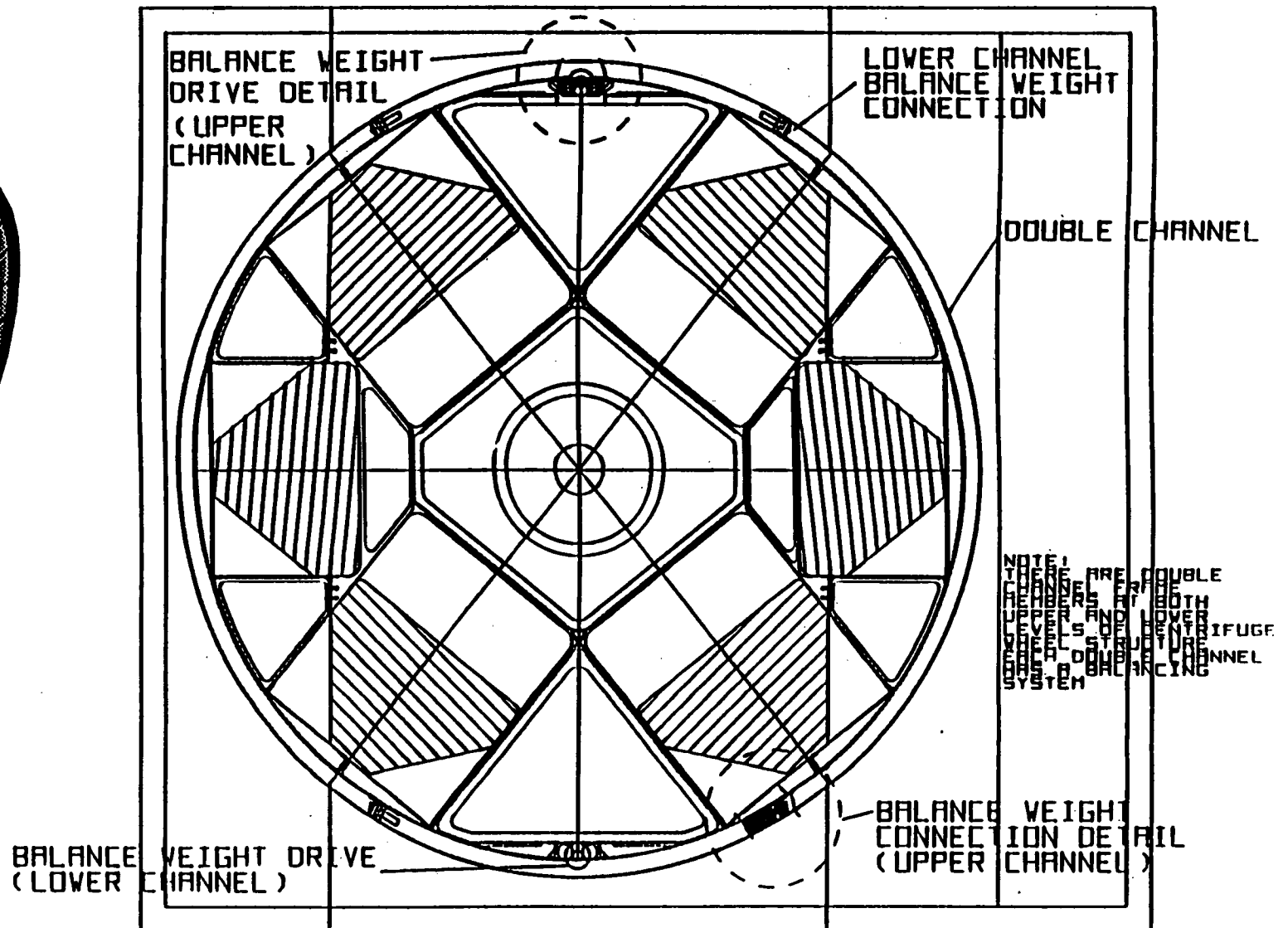
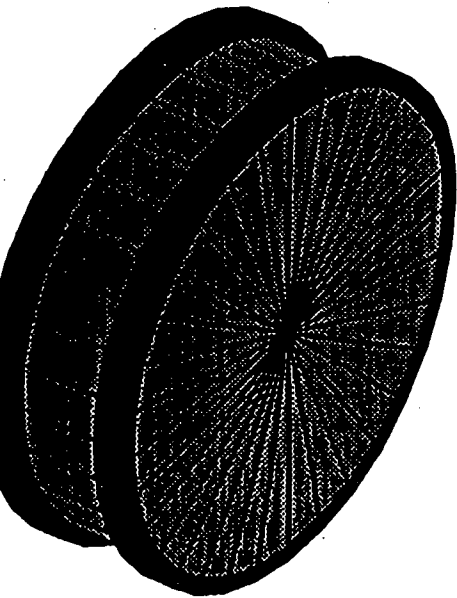
TWO PLANE
BALANCER SHOWN
THIRD AXIS OR
INTO PAGE OR
SAME SYSTEMS
REPEATED AT
BACK OF ROTOR

TRADEOFFS (CONT'D)

A radial balancer moves balance masses around the Centrifuge a fixed radial distance.

The view on the facing page depicts possible locations for the balance masses on the Centrifuge rotor. The isometric sketch to the left reveals the locations for this balancer mass both on the front and back surface of the rotor. The following views show some of the details of the belt mechanism and housing for the masses.

RADIAL BALANCER



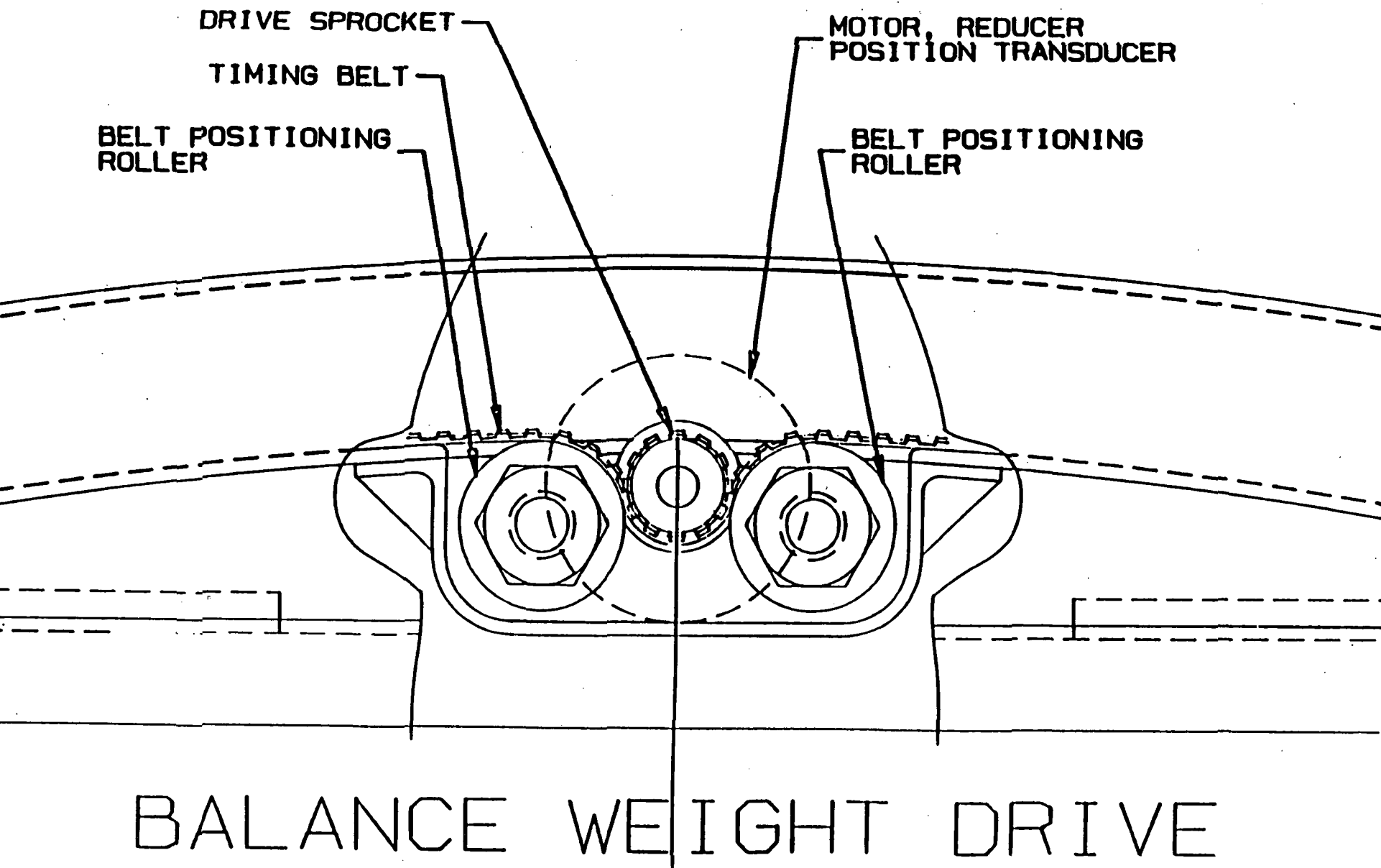
TRADEOFFS (CONT'D)

The exploded view on the facing page indicates how a timing belt may be used to rotate mass segments into position to counter mass imbalance. In this view the mass is depicted by the arcs above the timing belt. The motor and drive components are located on the periphery of the rotor.



RADIAL BALANCER

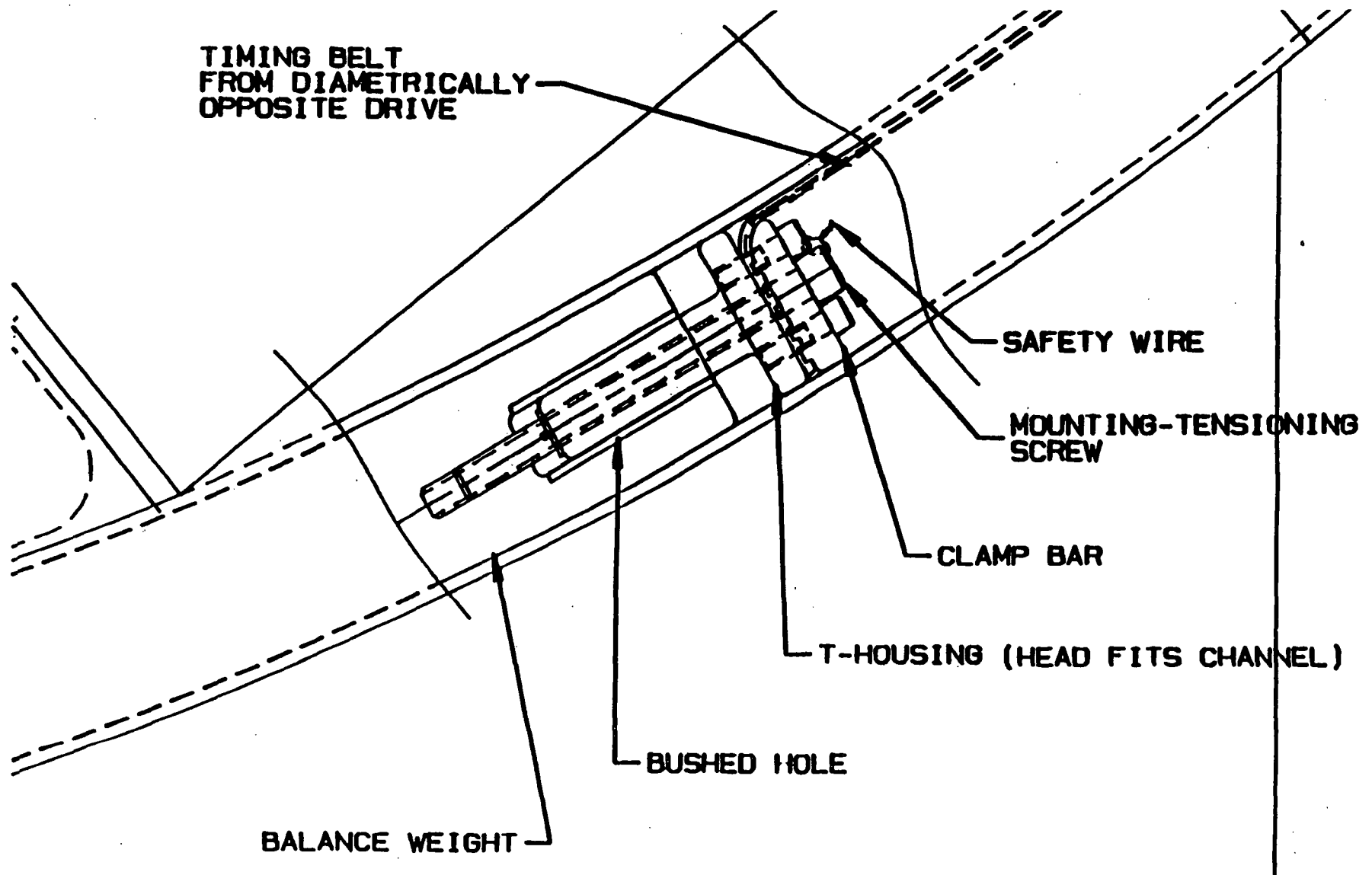
NASA / AMES RESEARCH CENTER



TRADEOFFS (CONT'D)

The exploded view on the facing page indicates how the drive timing belt clamps to the balance weight. This permits on orbit assembly if required.

RADIAL BALANCER



TRADEOFFS (CONT'D)

The volume constraints in the 74.5 in. rack lead to tradeoffs between subsystem components and an extractor; the reference design has no extractor. However, a continued effort at ARC is determining viable options to extractors; currently ARC has developed test beds for a radial and an axial extractor. Various extractor concepts are illustrated on subsequent pages.

These systems will be studied further for larger Centrifuges.

EXTRACTOR TRADEOFF

Radial (type 1)	Axial (type 2)	None
<ul style="list-style-type: none"> + Doesn't violate aisle space - Requires rotor ID to be open space to allow extraction - Fluid and power connections must be made at the base of the habitats - Limits the size of habitats that can be extracted + No additional, special structure for extractor - Forces on specimens change during extraction 	<ul style="list-style-type: none"> - Violates aisle space during extraction + Rotor ID can store equipment and consumables + Fluid and power connections must be made at the rear of the habitats + Can support wider range of habitat sizes - Requires safety shield and complex support system + Forces are constant during extraction 	<ul style="list-style-type: none"> + Doesn't violate aisle space + Rotor ID can store equipment and consumables + Fluid and power connections can be made at the rear of the habitats + Can support wide range of habitat sizes + No additional, special structure - All habitats stop during extraction

Current Choice: No extractor due to limited volume in 74.5 in rack. Larger Centrifuges have the potential for extractors.

TRADEOFFS (CONT'D)

A radial extractor operates within the rack envelope, but does not fit well with the overall system and limits habitat height. Other disadvantages are the loss in usable volume swept out by the extractor and complexities in locating connectors on the habitats. The location of connectors on Habitats designed for a Centrifuge with a radial extractor is incompatible with the location required for the Holding and Glovebox Systems without some initial axial extraction.

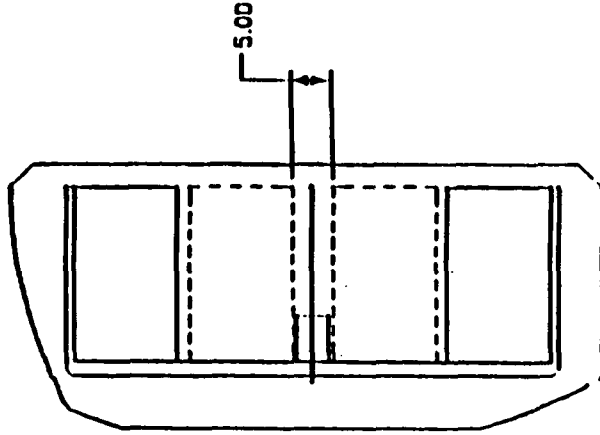
The axial extractor extends a large, enclosed framework into the aisle. This framework provides secondary containment for the habitats which are being extracted. It also prevents objects from floating into the rotating device and protects the crew from the rotating hardware. The central area of the rotor can be used for packaging additional hardware and habitat height is not as limited as with the radial extractor. This extractor type has connectors compatible with the Glovebox and Holding System.

Both extractor types are depicted in the following view with a few characteristics associated with the extractor listed below it.

EXTRACTOR TYPES

Extractors breadboarded at Ames:

HABITAT EXTRACTOR TYPES



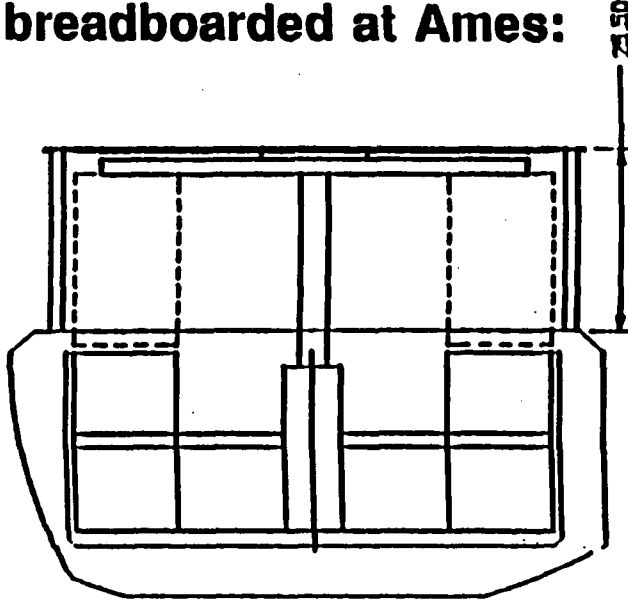
TYPE 1

LIMITED SPACE FOR EXTRACTOR
THEREBY REQUIRING SMALLER
HABITATS

REQUIRES SUPPORT OF ENTIRE
CENTRIFUGE AT ONE END
(CANTILEVERED)

FLUID AND POWER CONNECTIONS
MUST BE MADE AT THE BASE OF
THE HABITATS

COUNTER ROTOR MUST BE
INSTALLED BEHIND MAIN ROTOR



TYPE 2

REQUIRES VIOLATING AISLE SPACE

SUPPORTS AVAILABLE AT BOTH ENDS

REQUIRES SAFETY SHIELD AND
COMPLEX SUPPORT SYSTEM

CAN SUPPORT WIDER RANGE OF
HABITAT SIZES

CLUTCH AND DRIVE MECHANISM MAY BE
INTEGRATED INTO CENTER SHAFT

COUNTER ROTOR MAY BE INSTALLED
WITHIN THE MAIN ROTOR VOLUME

TECHNOLOGY DEVELOPMENT

The Centrifuge is viewed as a system which requires minimal technology development before it can be built. Areas where some development may be required are shown on the facing page. In each case the basic technology exists, only refinements to existing designs are required.

TECHNOLOGY DEVELOPMENT

- Development work of active vibration isolation systems for ultra low frequency and high frequency if required
- Development of "Roll Ring" power transfer joint with appropriate size and speed characteristics
- Development of rotary fluid and air joint
- Develop reliable quick disconnects to provide bioisolation
- Develop reliable liquid separators for long term operation

REQUIREMENTS NOT MET AND CONCERNS

For the design presented in this report, negative pressure is not maintained during replacement of the Contaminant Removal System for the spent CRS.

The primary science requirement not met by the baseline was the capability to remove two Habitats while the remainder are maintained at the desired gravity level. Although this capability could be included, it was felt that the penalty in the radius to the bottom of the Habitats associated with the addition of an extractor was too high. Subsequent to the completion of this study, larger Centrifuge designs have been considered. For these designs an extractor has been included. A second science requirement not met was to do servicing of the Habitats of the Centrifuge. Operational and contamination safety constraints appear to prevent meeting this requirement

Other requirements not met are associated with engineering and safety issues. It is anticipated that these issues can be resolved during the detailed design/development process.

2-3

REQUIREMENTS NOT MET AND CONCERNS

- No auto extractor is provided
 - Rotor must be stopped for habitat change-out
- Food replenishment, waste recovery and other habitat manipulations must be performed at the Glovebox.
- Direct viewing will require removal of the safety shield in the event of loss of power
- Two levels of bioisolation during all operations
 - One level during CRS change-out
 - Small contaminated surface areas of the connectors may be exposed for brief periods of time during change-out

REQUIREMENTS NOT MET AND CONCERNS

This page is a continuation of the list of concerns in the development of a Centrifuge. These are areas where further development efforts are required.

REQUIREMENTS NOT MET AND CONCERNS

- Vibration and acoustic noise levels
- Define mass balancer capabilities and limitations
- Momentum compensation - determine need for a counter rotor
- RF slip ring meeting size and bandwidth requirements needs to be located (off-axis design)
- Ability to clean any contaminated volume (ducting)
- Reliability and effective operation of liquid separators
- Long term degradation of quality of water supply
- Effectiveness and life of quick disconnects in maintaining bioisolation
- Develop interface plate locking mechanism that uses less space in the habitats
- Bioisolation
- Ability to clean and servicing time
- Temperature and humidity control

SUMMARY

The Centrifuge system design presented in this report would meet the requirements for providing resources for habitats in a variable gravity environment. The technology to meet this requirement with few exceptions has been demonstrated in existing systems which include both space hardware and commercially available hardware.

To fit all the necessary hardware to support the required number of specimens in two double racks will be difficult. There are factors such as the sizing of the waste liquid storage tanks which may help alleviate this problem. If the Centrifuge were to plumb directly to a Freedom waste processing system, then useful liquid may be extracted from the waste and storage volume on the Centrifuge may be reduced.

This system has been designed for the Space Station Freedom as baselined prior to June 1989. Should Freedom provided resources diminish, the design presented would be impacted and the experimental capabilities would need to be reduced to provide volume for additional hardware to compensate for the reduced Freedom resources. If the resources are provided, a Centrifuge similar to that which has been presented would provide the necessary accommodations for habitats in a controlled variable gravity environment.

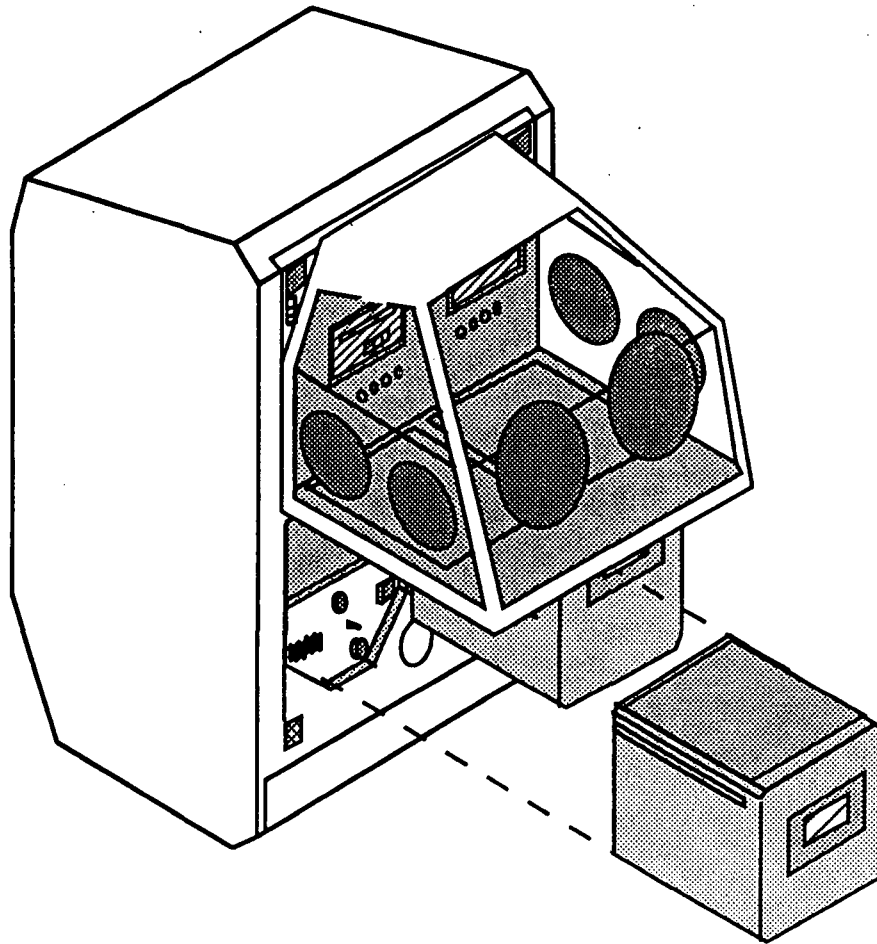
SUMMARY

- System design meets most requirements
- Required technology already demonstrated with exceptions previously noted
- High packaging density for Centrifuge hardware
- System requires large amount of supplies and processing of consumables support from Freedom
 - Ultrapure water
 - Gas tank recharging at high pressure
 - Processing of waste materials and liquids
 - CRS canisters and filters

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 7

Life Science Glovebox



INTRODUCTION

The facing page presents an outline for the Life Sciences Glovebox chapter of this report.

OUTLINE

- Primary Requirements
- System Description
- System Characteristics
- System Interfaces
- Tradeoffs
- Technical Issues/ Analyses
- Operations
- Technology Development
- Requirements Not Met
- Summary
- Appendix

PRIMARY REQUIREMENTS

The primary purpose of the Glovebox is to provide a fully enclosed environment for all specimen handling and experiment protocols requiring crew support. Although live specimens will be brought into the work volume periodically, the Glovebox design must be optimized to support operations rather than to serve as a long term living environment for the specimens. Scientists who may design or perform experiments that would require use of the Life Sciences Glovebox have been surveyed and the facing page presents a summary of their salient requirements.

The Glovebox environmental control system must provide temperature control between the range of 15°C to 35°C. Relative humidity control is not required.*

Air within the work volume must be able to sustain life without causing deleterious effects to the health of the specimens. The air quality must meet the same SMAC (Spacecraft Maximum Allowable Concentration) standards defined for the crew cabin air. Precautions must be taken to prevent microbial cross contamination between the specimens and crew, and HEPA (High Efficiency Particulate Air) quality filters must process air entering the work volume.

There will be a wide variety of operations performed in the Glovebox, involving various specimens, equipment, radioactive and nonradioactive materials, and procedures. Many of these operations must be performed by more than one person so the Glovebox must accommodate two crew members such that they can work together or separately.

* These two requirements reflect changes from the original release of the Phase B Specification and will be reflected in a future release of this document.

PRIMARY REQUIREMENTS

Science requirements that affect the design:

- Accommodate simultaneous access by 2 pairs of hands
- Prevent microbial cross contamination
- Control temperature from 15°C to 35°C
- Control of relative humidity not required
- Meet SMAC standards for air quality
- HEPA filter air
- Maintain gas composition suitable for life support
- Limit acoustical noise
- Accommodate specimens, equipment, procedures and materials
- Accommodate operations with radioactive materials

PRIMARY REQUIREMENTS (CONT'D)

Requirements that must be satisfied to enhance the functional capability of the Glovebox are summarized on the facing page. These requirements are derived from the Centrifuge Facility Phase B Specification.

To facilitate operations, the Glovebox must accommodate 2 Modular Habitats. In addition, laboratory support and experiment specific equipment housed in equipment modules similar to Habitat modules must also be accommodated

Crew satisfaction with the Glovebox will depend on the degree to which human factors considerations are incorporated in the design. This includes accommodating the anthropometric needs of users ranging from the 5th percentile Japanese female to the 95th percentile American male.

The Glovebox design must maintain a high degree of bioisolation. It must meet the standards for a Class III biological safety cabinet as defined in the "Laboratory Safety Monograph", January 1979 produced by the NIH. However, the requirement for a sterilizing pass involving a dunk bath with liquid disinfectant is waived for the Life Sciences Glovebox. In addition to the NIH specifications, the Glovebox must meet the bioisolation requirements that are called out in the Centrifuge Facility Phase B Specification.

Many operations involving servicing of the Habitats may need to be performed at the Glovebox. These operations would include: changing of components of the Habitats such as food cassettes and electronics modules, manual cleaning of plant specimen chambers, and replacement of dirty specimen chambers with clean ones.

After each use, the Glovebox will need to be cleaned. The design of the Glovebox must be optimized to facilitate cleaning and decontamination. Hazardous materials and waste products need to be collected in a safe manner.

PRIMARY REQUIREMENTS (CONT'D)

Functional requirements that effect the design:

- Simultaneously accommodate 2 Habitats and/or equipment modules
- Provide capability for hazardous waste management and collection
- Satisfy anthropometric requirements of the users
- Facilitate maintenance, cleaning, and decontamination
- Operate at microgravity levels and on Earth
- Class III biocontainment (except sterile or clean pass through)
- Provide for routine servicing operations for the Habitats
- Maintain bioisolation during all operations

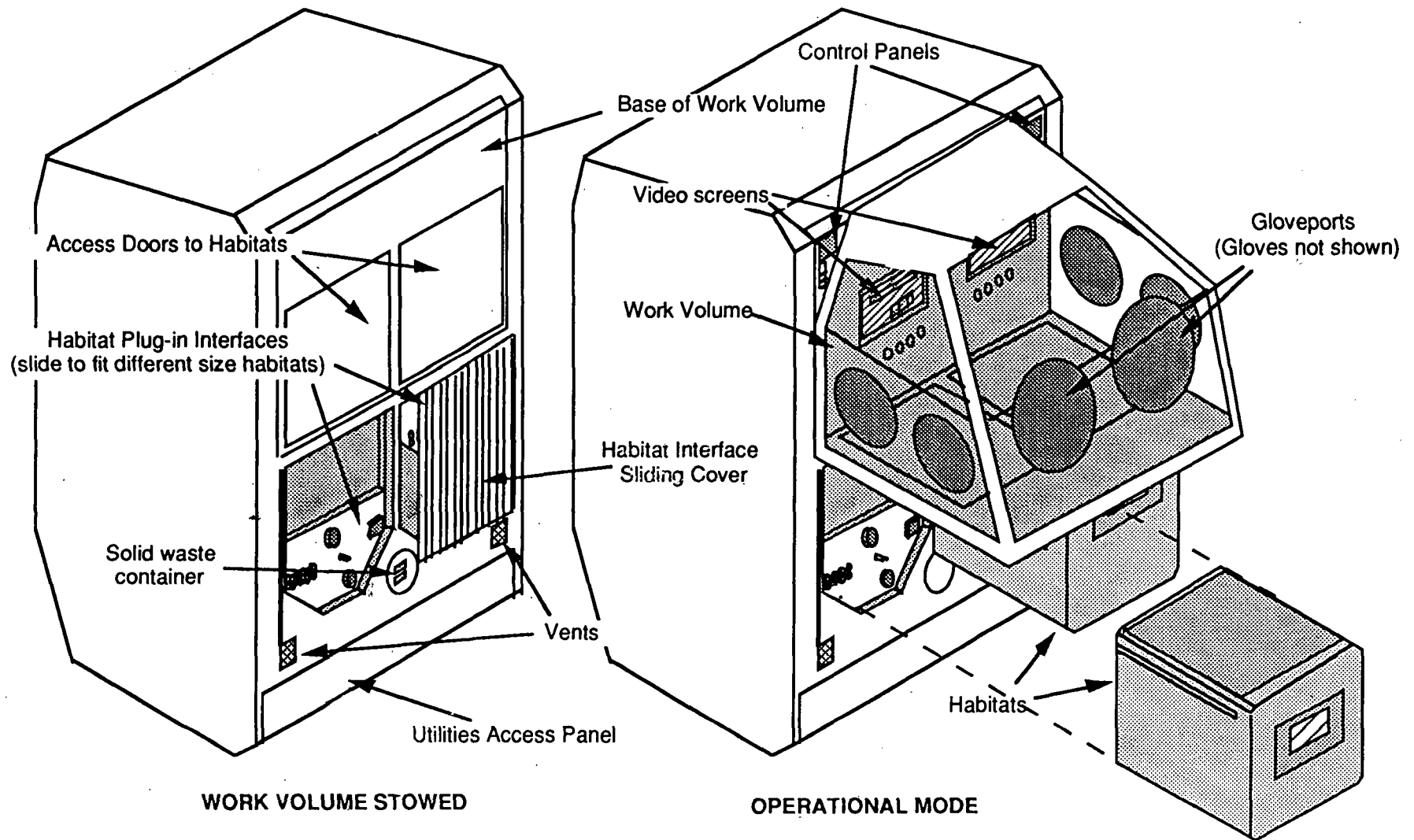
SYSTEM DESCRIPTION

The isometric view of the Life Sciences Glovebox depicts the Glovebox in non-operational and operational configurations. When the Glovebox is not in use, the fully enclosed work volume stows within the rack. When the Glovebox is operational, the work volume folds down from the rack and can be used by up to 3 people.

The picture on the left shows the Glovebox in the non-operational mode. The interfaces to the Habitats are covered by a sliding door when no Habitats are attached. This is to protect the crew from the protruding end of the quick disconnects and the threaded rod that is part of the Habitat mating device. When a Habitat is attached, the door is rolled away and the interface plug-in panel is slid to the correct position for the particular Habitat type. Below the Habitat plug-in panels, inlet and outlet vents, and the solid waste container, and a utilities access panel are shown.

The picture on the right shows the Glovebox in the operational mode. The work volume is ready to be used. Surrounding the work volume are circular gloveports. Sealed gloves are attached to the gloveports, but for the sake of clarity, they are not shown in this drawing. In lieu of gloves, bags or containers can be attached to the gloveports for transport of materials. Once the work volume is pulled down, Habitats and equipment modules can slide underneath along a set of parallel supporting rails and plug into the interface plates located on the front of the rack.

ISOMETRIC VIEW



SYSTEM DESCRIPTION (CONT'D)

The Life Sciences Glovebox fits within the envelope of a 74.5 inch Space Station Freedom rack. The work volume is a hinged, rigid, fully enclosed unit that is deployed into the cabin aisle when used. The Glovebox can be controlled via control panels mounted external to the work volume, or a deployable touch panel inside the work volume. A video display screen, and power, data, and vacuum utility connections are also found within the work volume.

Inlet air is HEPA filtered and conditioned to the desired temperature prior to entering the Habitats or work volume. Air vented from the Glovebox must pass through multiple charcoal and HEPA quality filters before entering the cabin. Charcoal filter beds are accessed from the rear of the rack, while other expendables are accessible from the front.

Operations within the work volume are performed with two layers of bioisolation separating the crew from the specimens. One layer is the physical barrier provided by the work volume walls, the second layer is the 0.5 inches H₂O negative pressure of air within the work volume.

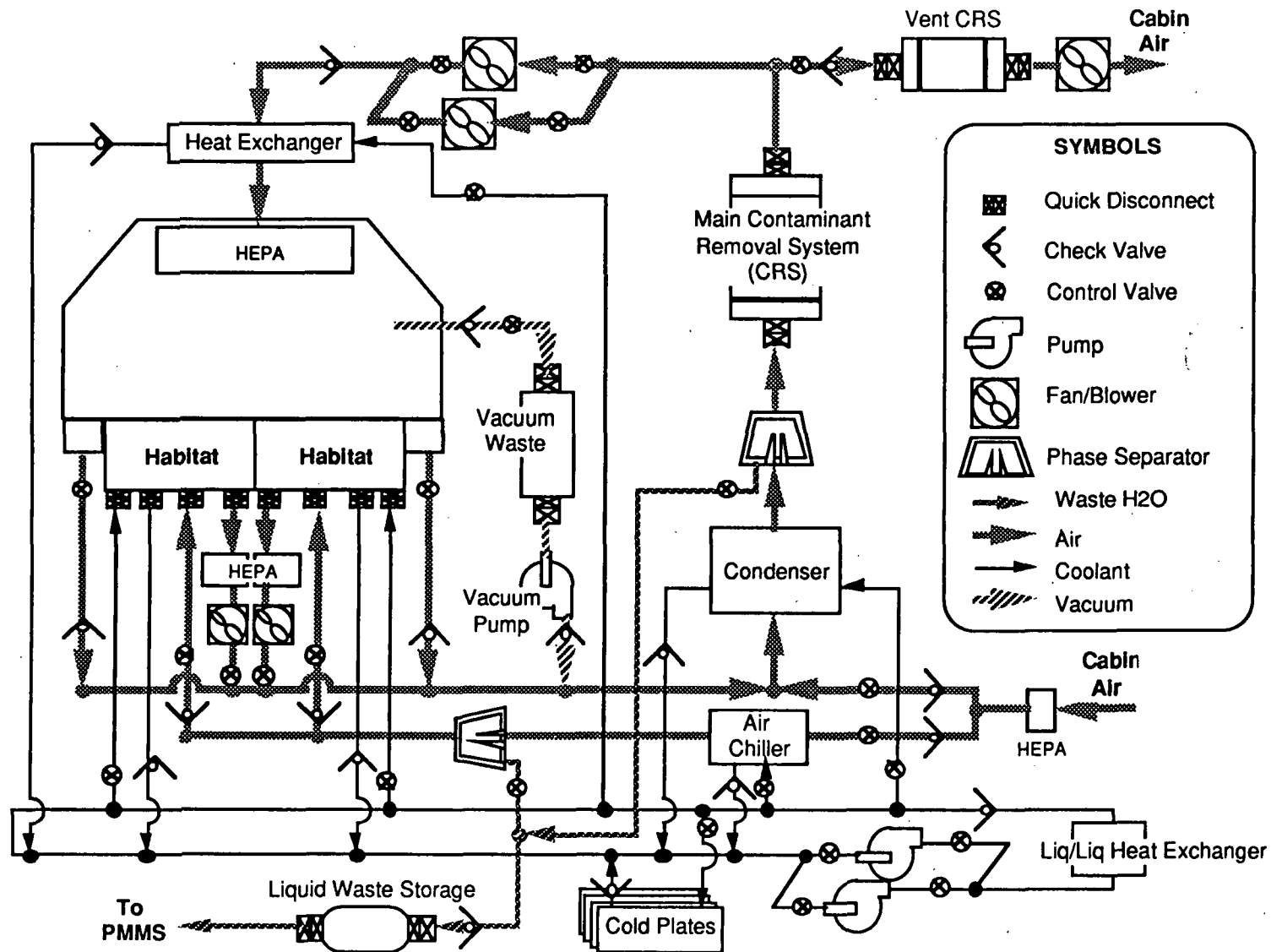
SYSTEM DESCRIPTION (CONT'D)

- Class III, fully contained, constant volume glovebox work volume
- Hinged work volume
- Six gloveports
- Accommodations for 2 habitats of any size
- Sliding habitat plug-in interface panel to accommodate different habitat sizes
- Equipment transferred via habitat-size modules
- Video display screens and control panels inside and outside of work volume
- Gloves and trash bags fit gloveports
- Expendables accessed from front and rear of the rack
- Two levels of bioisolation maintained during operations within work volume
- HEPA and charcoal filtration of the air

SYSTEM DESCRIPTION (CONT'D)

This block diagram highlights the different subsystems found within the Glovebox. It illustrates the pathways followed by air, coolant, waste water, and vacuum waste, as well the primary components of the Glovebox. More importantly, it provides an overview of the Glovebox system, detailing how the different subsystems interact. In the following pages, each subsystem is detailed in separate block diagrams for greater clarity.

LSG BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The air in the work volume is changed at the rate of 50 air changes per hour which corresponds to a flow rate of 7000 cc/s (15 cfm). Air exiting the work volume passes moisture absorbing pads that prevent liquid spills from entering the ducting. After passing through the pads, the air mixes with 1500 cc/s (3 cfm) of air which comes from the cabin and the 2 Habitats. This 8500 cc/s (18 cfm) stream of air passes through an air/water heat exchanger that chills the air and condenses the water vapor. Condensate is removed by the centrifugal action of the rotating phase separator. The air then passes through the activated charcoal in the Contaminant Removal System (CRS) canister where trace contaminants are removed.

After passing through the CRS, the air splits into two streams. The main air flow stream is redirected through a HEPA filter to the work volume by a set of blowers. A separate air flow path is drawn through the Vent Contaminant Removal System (VCRS) by a fan which exhausts clean air to the cabin at a rate of 1500 cc/s (3 cfm). The VCRS removes any trace contaminants that were not removed by the main CRS, and contains inlet and outlet HEPA filters within the canister.

The blowers are located to pull air through the various filters. This ensures that negative pressures are maintained within all contaminated regions of the air stream including the work volume. Check valves and control valves are located throughout the system to eliminate back flows and control flow rates.

WORK VOLUME AIR FLOW

- 50 air changes per hour within Glovebox work volume
- Before entering the work volume, recirculated air passes through:
 - Moisture absorbent pads to collect liquids
 - Air/water heat exchanger to condense vapors
 - Phase separator to remove condensate
 - Contaminant Removal System (CRS) to remove trace contaminants
 - Fan to circulate the air
 - Another air/water heat exchanger to control air temperature
 - HEPA filter before re-entering the work volume
- 1500 cc/s (3 cfm) of exhaust air vented to cabin after passing through an additional CRS
- Cabin air provides 1500 cc/s (3 cfm) of make-up air filtered through a HEPA filter

SYSTEM DESCRIPTION (CONT'D)

Approximately 500 cc/s (1 cfm) of air is provided for each Habitat. The air provided to each Habitat is pulled from the cabin environment and chilled to the desired temperature by an air/water heat exchanger. Any condensate formed by the heat exchanger is removed by a phase separator.

Air exiting from each Habitat flows through a HEPA filter and fan prior to mixing with air from the cabin and work volume. The fan is provided to equalize the pressure of air from the Habitat with the pressures of the cabin and work volume air. The air then passes through a condenser, phase separator, and CRS canister. Following this, some of the air is redirected into the work volume while the remaining air is vented to the cabin.

Spills of toxic substances require the Glovebox to operate in a fully closed-loop air flow mode. All of the air is continuously recirculated until it is completely processed by the filters. The vacuum blower is activated, creating a large negative pressure to collect fluids. The air drawn through by the vacuum passes through a coarse filter prior to entering the condenser, phase separator, and main CRS to decontaminate the air stream. Since the Glovebox is operating in a fully closed loop mode, no air from the cabin is taken in. For this reason, no air can be provided to the Habitats, and the Habitats must be removed from the Glovebox.

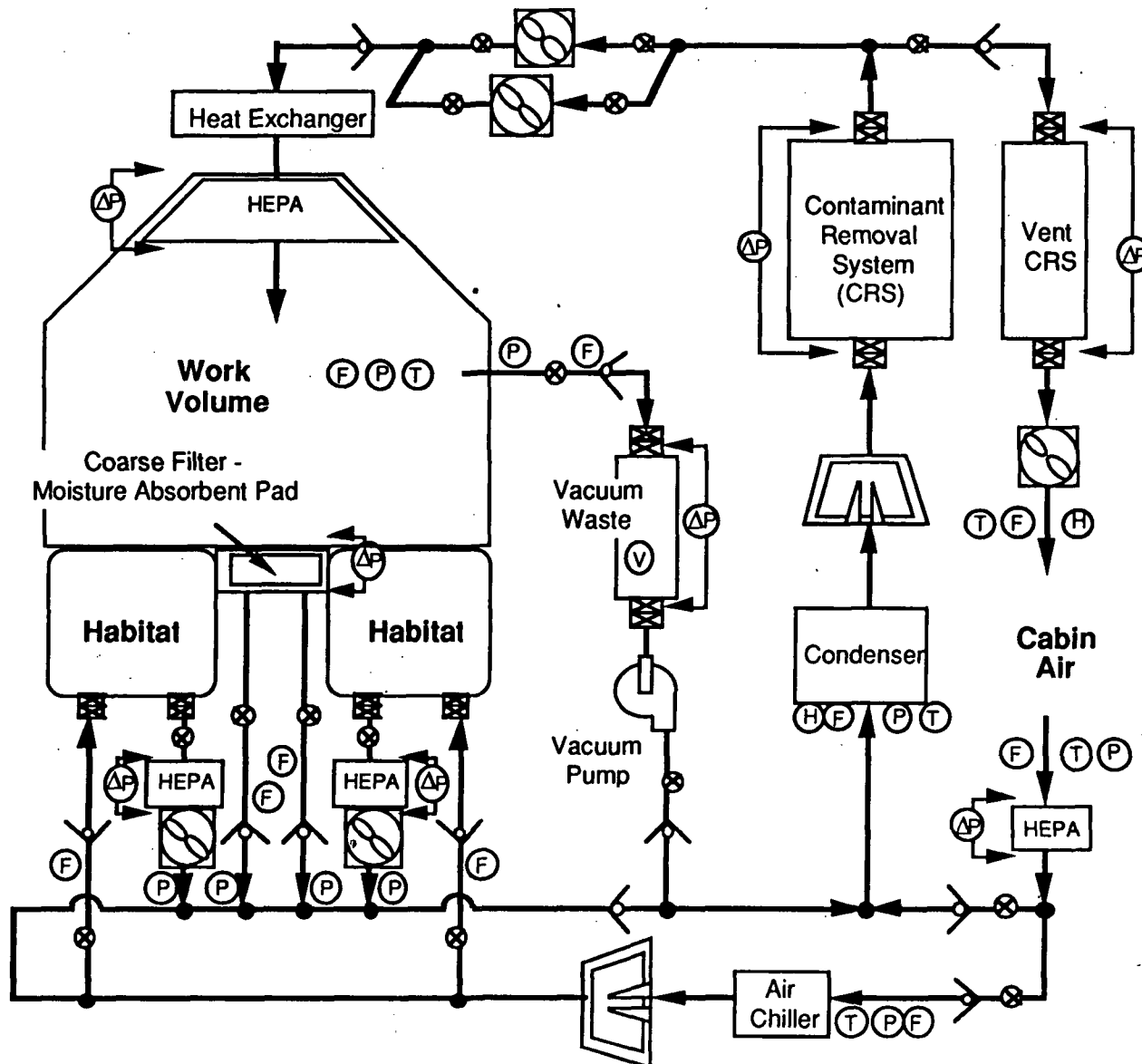
HABITAT AIR FLOW

- Air to the animal habitats is circulated through a HEPA filter, heat exchanger, and phase separator
- Approximately 500 cc/s (1 cfm) of air flow per animal Habitat
- Exhaust air from habitats is circulated through a HEPA filter, condenser, phase separator, and the main Contaminant Removal System (CRS) canister
- During clean up of toxic spills, air flow from habitats is shut off and air from the work volume is recirculated

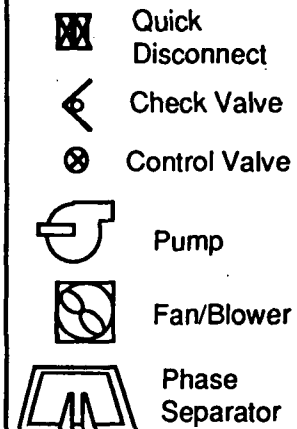
SYSTEM DESCRIPTION (CONT'D)

The following is a diagram of the air flow through the Glovebox. The legend for the diagram is on the right hand side of the chart. The diagram illustrates the pathway followed by the air stream. Sensor and equipment location are also depicted.

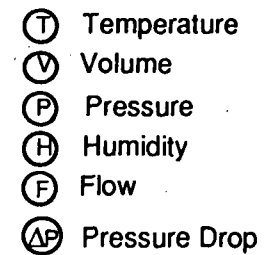
AIR FLOW BLOCK DIAGRAM



SYMBOLS



SENSORS



SYSTEM DESCRIPTION (CONT'D)

Most of the Glovebox thermal dissipation will be via the Freedom 4°C coolant loop. A block diagram and description of this cooling system follows. The Glovebox interface to the loop is through a water-to-water heat exchanger located at the bottom of the rack. A separate closed loop water line runs within the rack and rejects heat to the Freedom coolant loop via this heat exchanger. The coolant also flows through air-to-water heat exchangers that provide thermal and humidity control of the air flow. The Glovebox coolant flows through cold plates that are attached to electronic components which require cooling. Control and check valves are located throughout the coolant loop to control the flow and direction of flow of the coolant.

Avionics air will be used to cool areas that are inaccessible by coolant lines or components that have a low thermal rejection load. The avionics air enters the rack through an opening at the top of the rack. Exhaust is through a connection at the bottom of the rack.

Cabin air will absorb the heat load from exhaust fans and some thermal energy that radiates from the work volume when the lights are on.

A combination of liquid coolant and cabin air is used for thermal control of the various Habitats*. The Habitats are provided with the liquid coolant by the Glovebox liquid coolant loop.

*Recent information from the Freedom Program indicates that severe constraints have been placed on cabin air heat loads. Therefore this feature of the design will have to be modified.

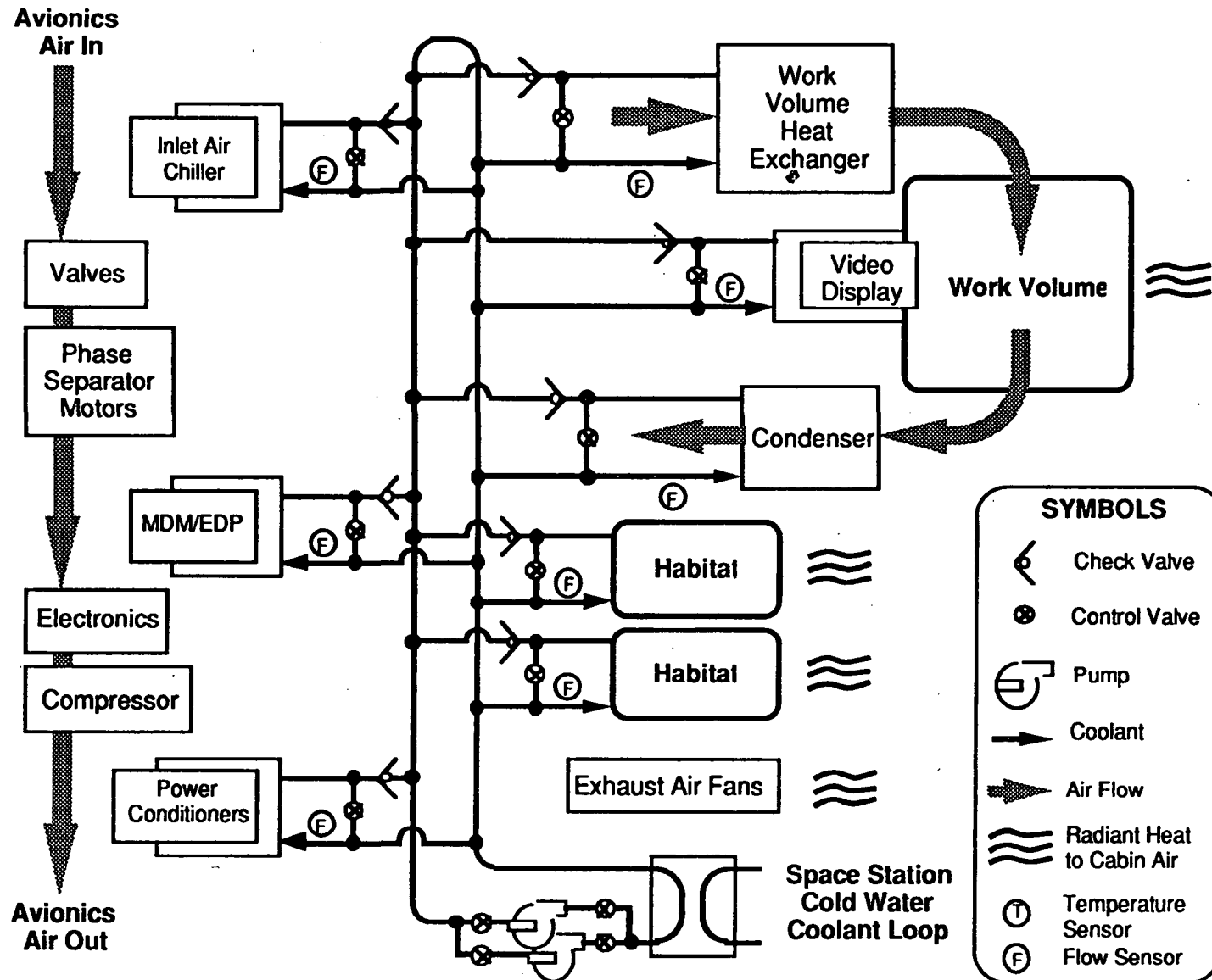
THERMAL CONTROL

- Coolant water cooled within water/water heat exchanger provided by the Space Station
- Water/Water heat exchanger interfaces with the Space Station 4°C water loop
- Coolant circulates through:
 - Air/water heat exchangers - air chillers, condensers
 - Habitats
 - Cold plates used to cool MDM/EDP, power electronics, video display terminals
- Avionics air within rack cools the electronics requiring low power
- Cabin air absorbs thermal energy from the exhaust air, habitats, and thermal energy radiating from the work volume

SYSTEM DESCRIPTION (CONT'D)

A block diagram of the Glovebox cooling system is depicted on the facing page. The legend to the diagram is on the lower right hand corner of the page. The diagram illustrates how avionics air and coolant water is used to cool Glovebox components. Avionics air is symbolized on the left hand side with thick dark grey arrows. Coolant water is represented by solid black lines. Coolant water either passes through cold plates bolted to electronic components such as the video display, or through air/water heat exchangers. Air circulating through the work volume is cooled by the work volume heat exchanger and the condensing heat exchanger. Some heat from the work volume and Habitats radiates to the cabin.

THERMAL CONTROL BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

Freedom supplies electrical power to the users at 120 VDC. This power passes through a Power Protection Assembly (PPA) which controls power input to the rack and provides a circuit breaker for protection. Power is then transferred to the power electronics which converts the raw voltage to different AC and DC voltages. The power electronics are assumed to have an efficiency of 90%.

A battery is provided for memory maintenance and is recharged by power supplied by Freedom.

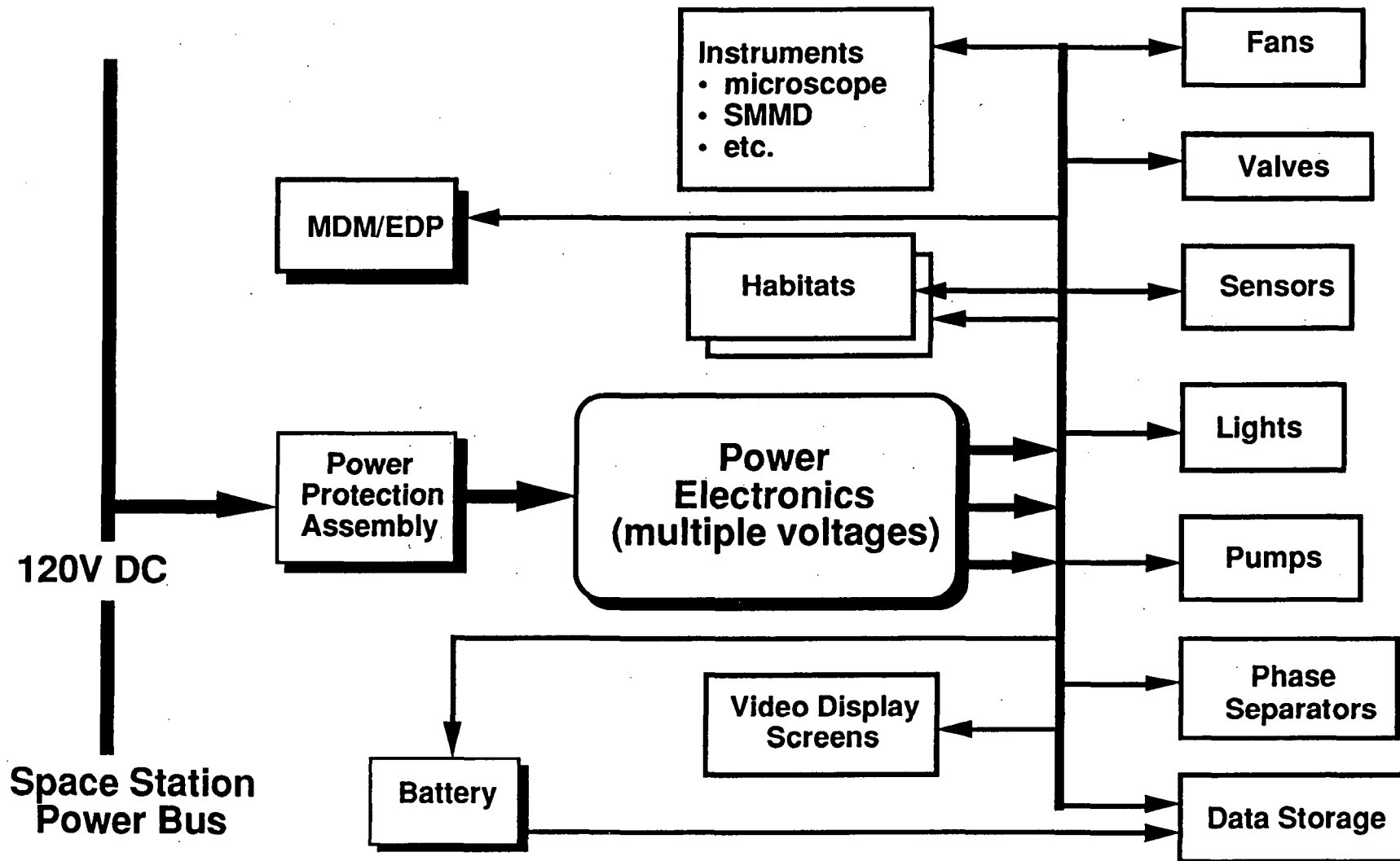
ELECTRICAL

- Power Protection Assembly (PPA) controls power entering the power electronics
- PPA is controlled by the MDM/EDP
- Power electronics convert the 120 VDC supply voltage to the desired AC and DC voltages
- Power electronics are assumed to be 90% efficient
- Battery unit provides back-up power for memory maintenance

SYSTEM DESCRIPTION (CONT'D)

The following chart illustrates the electrical connections within the Glovebox. The power electronics converts the raw Freedom supplied power into the voltage levels suitable for driving the different Glovebox components.

ELECTRICAL BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The central controller for data collection and transmission to Freedom is the Freedom supplied Multiplexer/Demultiplexer (MDM). Non-video data are transmitted to and from the Freedom data network via the Network Interface Unit (NIU). These data include data from the Habitats, engineering data from Glovebox subsystems, and scientific data generated by equipment inside the work volume. Data from the Habitats are received from hardwire transmissions.

Video data is generated by cameras located inside the Habitats, inside the work volume, and video microscopy equipment. The different video channels are connected to a video switcher that selects the desired channels for transfer to the Video Utility Panel (VUP) and Freedom video data bus. Besides one channel of output, the Glovebox requires one channel for video input.

The MDM incorporates the Embedded Data Processor (EDP) which provides control to the entire Glovebox system. Commands and control settings are input by crew members via control panels located inside and outside of the work volume. These commands are synthesized by the EDP, which sends signals to the appropriate actuators (valves, fans, pumps, etc.)

It should be noted that the EDP has been deleted from the Freedom Program subsequent to completion of this study. This feature of the design will have to be modified in future studies.

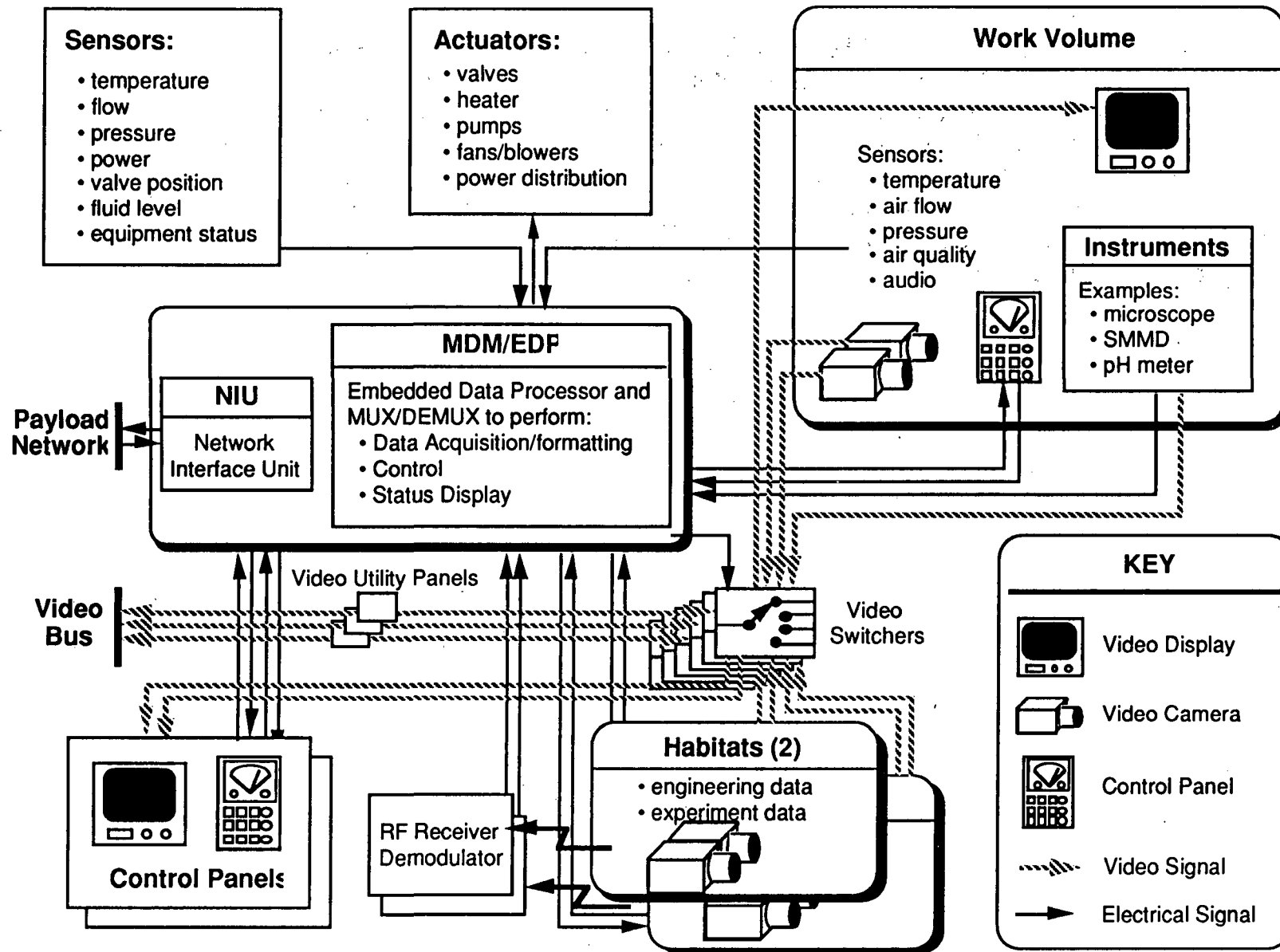
DATA

- MDM/EDP functions:
 - Controller
 - Multiplex/demultiplex data
 - Interface with DMS
- Engineering data generated by temperature, flow, pressure, and on/off status sensors
- Science
 - Data output from Habitats
 - Data from equipment within work volume
 - Audio data from users
- Video
 - 2 video cameras inside the work volume
 - 1 video channel for equipment within work volume (e.g. microscope)
 - 1 video channel provided for each Habitat
 - Video display screens located internal and external to the work volume
 - Video controller unit controls input/output of video data

SYSTEM DESCRIPTION (CONT'D)

The following diagram illustrates data flow within the Glovebox . The legend to the diagram is in the lower right hand corner of the page. Arrows indicate the direction flow of data and commands. Dashed lines represent video information, while solid lines represent all other types of transmissions.

DATA BLOCK DIAGRAM



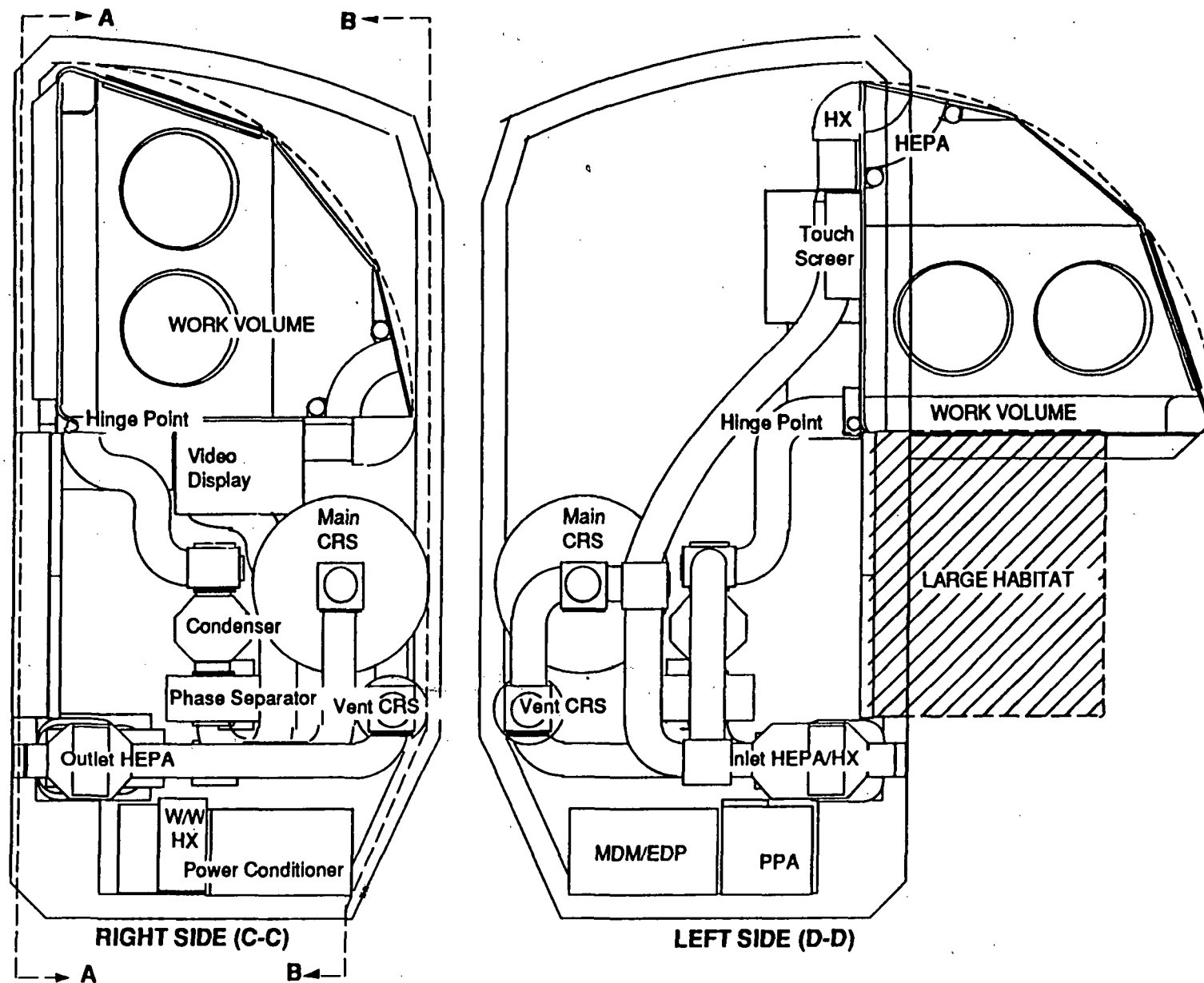
SYSTEM CHARACTERISTICS (CONT'D)

The left and right side section views of the Glovebox illustrate the layout of the major components. The side views show the Glovebox with the work volume stowed and with it deployed. When stowed, the work volume and its attached equipment, such as the video display, occupy the upper portion of the rack. The middle portion is filled with ducting and equipment that filter and condition the air. The main and vent Contaminant Removal System canisters are located in the back of the rack and are accessed by removing rack panels. Vents and waste storage containers are located at the front of the rack. The bottom of the rack is filled with Freedom supplied components such as the MDM/EDP and water-to-water heat exchanger.



SYSTEM LAYOUT

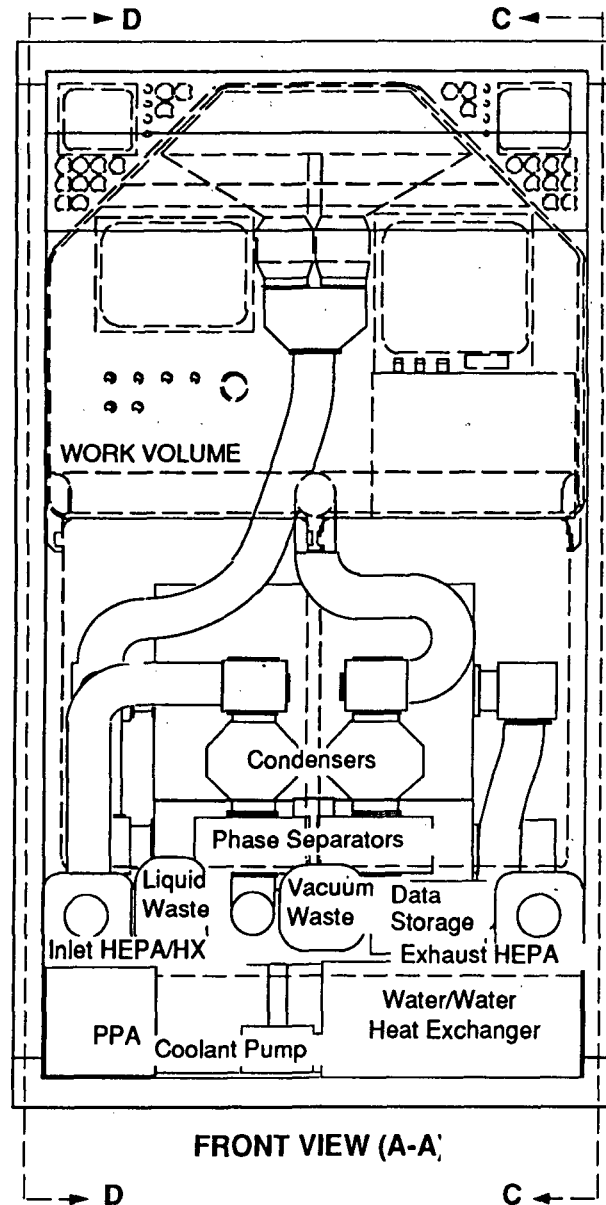
NASA / AMES RESEARCH CENTER



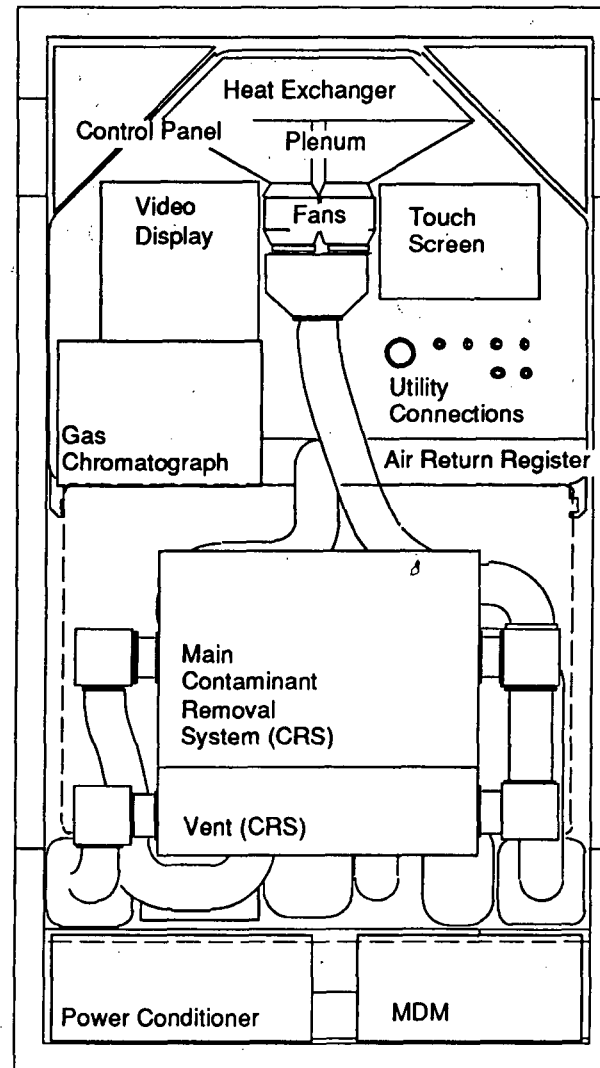
SYSTEM CHARACTERISTICS (CONT'D)

The front and rear section views of the Glovebox illustrate the layout of the major components. The top portion of the rack contains the equipment attached to the work volume. The rear section view shows the equipment located on the rear panel of the work volume. The front section view shows dashed outlines of the work volume equipment. Both views show the work volume in the deployed configuration.

SYSTEM LAYOUT



FRONT VIEW (A-A)



REAR VIEW (B-B)

SYSTEM CHARACTERISTICS (CONT'D)

The work volume of the Glovebox is a rigid walled, fixed volume unit that is fully enclosed. The work volume occupies approximately 0.44 m^3 (15 ft^3). The top of the work volume contains the air inlet plenum and inlet HEPA filter, as well as fluorescent and UV lights for illumination and sterilization, respectively. The bottom of the work volume is the primary work surface. The majority of the work surface is occupied by doors used to access Modular Habitats. At the front of the work surface is an air register. This register collects the exhaust air, which passes through ducting located on both sides of the work volume to a condenser and a series of filters. The register contains moisture absorbent pads that prevent liquid spills from entering the ducting.

Habitats and equipment modules slide underneath the work volume. Once the modules are properly mated to the plug-in interface panel, seals located underneath the work volume are inflated. These seals prevent any transfer of air between the modules and the cabin when the modules are opened to the Glovebox.

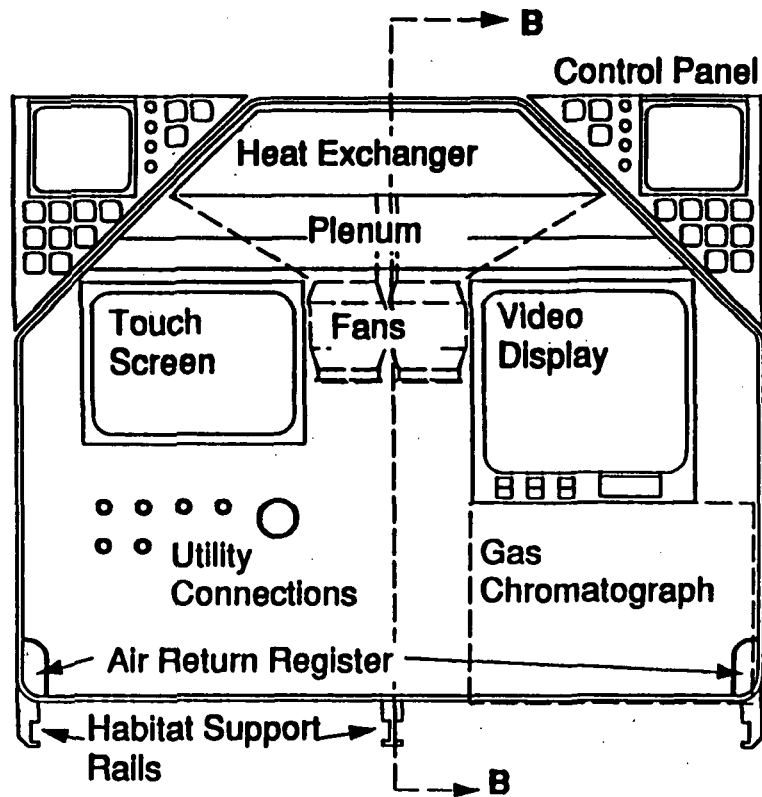
WORK VOLUME

- Rigid, fully enclosed unit that is hinged in one corner
- Work volume is approximately 0.44 m³ (15 ft³)
- Rotates about the hinge and stows inside the rack when not in use
- Rotates about the hinge and protrudes into the aisle when in use
- Air enters through plenum in the upper rear of the work volume
- Air exits through plenum in the lower front of the work volume
- Habitats and equipment modules seal to the underside of the work volume

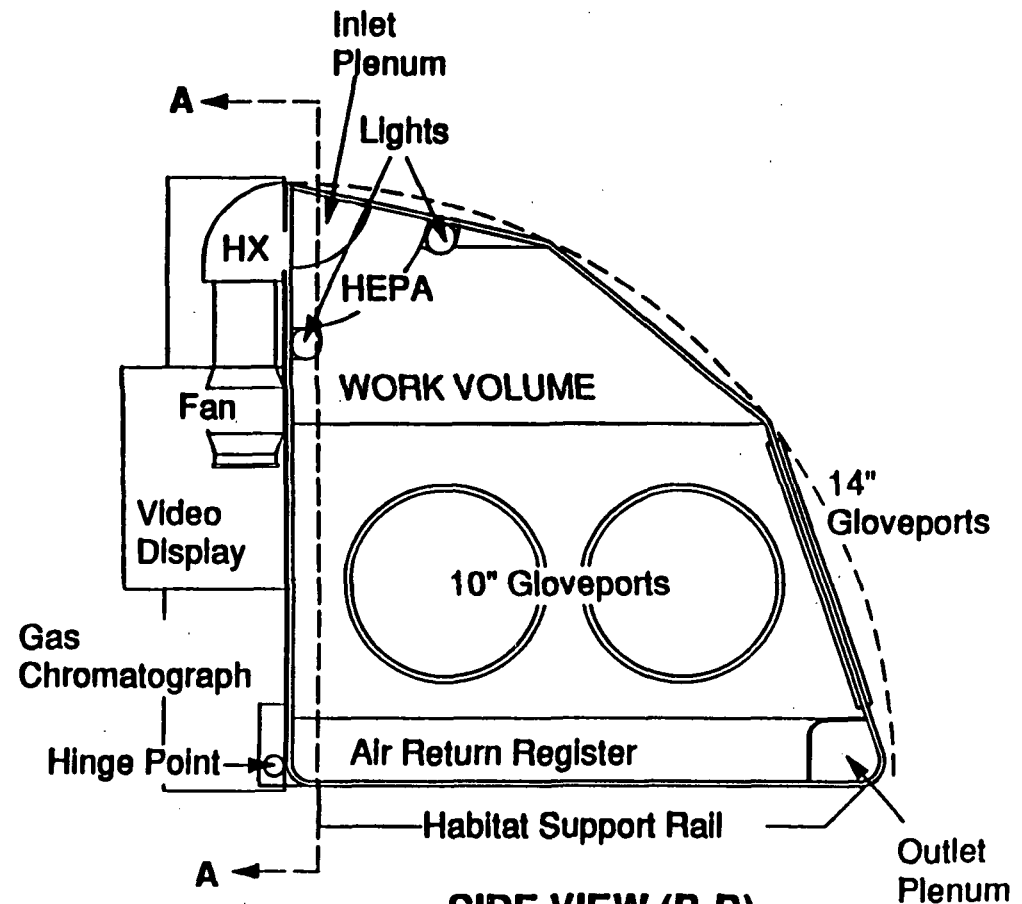
SYSTEM CHARACTERISTICS (CONT'D)

The work volume is a fully enclosed unit used for crew operations with animal and plant specimens. The major components of the work volume are illustrated in the following figure. The front view shows the various displays that could be used for crew operations and telescience. The control panels in the corners are external to the work volume and can be used by the crew to control Glovebox ECLS parameters. The gas chromatograph, video displays, heat exchanger, and fans are mounted to the back of the rear panel of the work volume. Rails are located underneath the work volume to support the Modular Habitats.

WORK VOLUME LAYOUT



FRONT VIEW (A-A)



SIDE VIEW (B-B)

SYSTEM CHARACTERISTICS (CONT'D)

The work volume contains equipment items to support operations. Two compact CCD cameras are mounted inside the work volume, one recording images from the top, another situated at the side. The video cameras will provide visual information to principal investigators (PI's) on the ground. Video images from these cameras or other sources can be displayed on the video display screen inside the work volume. The screen can also show video images uplinked from the ground from the PI's. Overall, video is essential for Glovebox operations. A testbed activity at ARC has demonstrated the value of two-way video for science protocol monitoring by the Principal Investigator. The results of the activity show that the availability of real-time two-way video can significantly enhance the value of on-board activities.

Lights are also positioned at the top of the work volume. One permanently fixed fluorescent light provides illumination for operations. A movable fluorescent spot light is provided to illuminate small areas. In addition, an ultraviolet light is mounted near the top and is used to limit microbial growth.

A color video display and gas chromatograph (GC) are mounted at the rear of the work volume. The chromatograph is similar to a miniature GC that is currently commercially available. The GC is used to monitor the work volume air quality via periodic sampling and analysis. A touch screen display panel is temporarily mounted at the rear of the work volume. This display panel can be removed from this location and placed anywhere inside the work volume to facilitate access by the crew. Connections for several utilities, including compressed nitrogen, power, and data, are also provided at the rear of the work volume.

For clean up, a vacuum connection is available, which can be used to remove liquid spills and small solid particles. An ultrapure water line is also provided to assist in cleaning. The quality of the water need not be ultrapure, but ultrapure water is the only water available to the users, according to the information from Freedom available at the time this report was written.

WORK VOLUME EQUIPMENT

- 2 video cameras
- Stationary and spot lights
- UV light to facilitate sterilization
- Rear mounted high resolution color video display
- Deployable touch screen display
- Wet-dry vacuum provided to clean-up spills
- Air register at bottom front of work volume contains an absorbent filter pad to catch solids and liquids
- Utilities provided in work volume:
 - Power
 - Data
 - Compressed nitrogen
 - Ultrapure water

SYSTEM CHARACTERISTICS (CONT'D)

The Glovebox is designed to enhance ergonomic accommodations for the users. The design of the Glovebox assumes crew members will be in the neutral body position when they are in a zero-gravity environment. The viewing windows on the side and front of the work volume are angled at 45° to avoid interference with the heads of the users. The knees of the users are afforded 28 cm (11 inches) of clearance between the front of the Habitats and front of the work volume.

The entire front and side surfaces are transparent to provide visibility inside the work volume. The color video display is fixed near the top of the rear wall to avoid visual obstruction from equipment placed on the Glovebox work surface. The touch screen panel can be removed from the back wall and stationed anywhere inside the work volume for easier operation. Small video displays and control panels are also situated external to the work volume for periods when the internal display and controls are inaccessible.

The diameters of the gloveports have been made large to increase the range of arm motion of the users. The front gloveports are 36 cm (14 inches) in diameter, while those on the side are 25 cm (10 inches) in diameter. Frequent glove changes will be required and a suitable technique for doing so has been identified. The technique allows glove change within a short period of time and decreases the number of surfaces exposed to the cabin environment. At no time during the glove change operation is there an exchange between cabin and Glovebox air.

The general approach followed by the designers of the Glovebox was to engineer the work volume for the largest size users and make special accommodations for smaller users. For example, the work volume was made as large as possible. With the baseline configuration, the 50th percentile American male can reach all interior surfaces from the front, but smaller users cannot. They must use extension tools to access all regions.

HUMAN FACTORS

- Users in the neutral body position are accommodated at the front of the rack
- Viewing windows angled at 45° to facilitate viewing
- Habitats recessed to clear knees
- Large window area provides direct line-of-sight to all areas
- Fold out bench/harness(es) or foot restraints used to restrain user(s)
- Video display screens mounted internal and external to the work volume
- Diameters of gloveports optimized for range of motion - 36 cm (14 inch) front ports, 25 cm (10 inch) side ports
- Gloveports accommodate different hand size and type of gloves, and rigid and flexible containers
- A quick glove change technique has been identified
- Design accommodates the larger size users; smaller users may require tools to extend their reach

SYSTEM CHARACTERISTICS (CONT'D)

Effectively maintaining bioisolation is the most critical function of the Life Sciences Glovebox. Bioisolation is achieved through two means: physical barriers confining contaminants, and negative air pressure (relative to cabin pressure) in contaminated regions.

In the Glovebox work volume, the environment is fully enclosed, including sealed gloves in the gloveports. Air can enter and exit the work volume only through filtered pathways. The work volume meets the standards specified for Class III Biological Safety Cabinets except that it does not have a sterilizing pass-through. In case the physical barrier is breached (e.g. a hole in a glove), the internal environment is maintained at a 13 mm (0.5 inch) water negative pressure to ensure that no work volume air escapes into the cabin.

All air within the work volume, Habitats, and ducting is considered contaminated by microorganisms, hazardous chemicals, and waste matter until it has been processed. This air is decontaminated by a condensing heat exchanger, phase separator, multiple HEPA filters, and treated activated charcoal. All the aforementioned areas are maintained under a negative pressure of at least 13 mm (0.5 inch) water. Air exhausted to the cabin must be processed by 2 Contaminant Removal System canisters before being vented to the cabin environment.

To move equipment and specimens in and out of the work volume, habitats or habitat-like equipment modules must be used. The modules seal to the underside of the work volume, preventing any direct air exchange during the transfer process.

The gloveports can also be used as a transfer system. Special bags can be attached to the gloveports in place of gloves. The bags are turned inside-out to protrude into the cabin from the work volume and can be used to deposit material such as garbage and sample containers. Once a bag becomes full or its use is completed, the open end of the bag is heat sealed. The bag is cut through the middle of the heat seal and can then be transported to the appropriate storage area. The remainder of the bag can be used again or it can be replaced by a glove or another bag using the same technique used for glove change. A similar bagging process can be used to transfer small items into the work volume.

BIOISOLATION

- Two layers of biocontainment maintained during all work volume operations
 - Fully enclosed work volume is primary layer of biocontainment
 - Negative pressure is an additional layer of biocontainment
- Negative pressure maintained in all contaminated regions
- Air exhaust to cabin passes through 2 CRS canisters
- Specimens and equipment brought in/out of work volume via habitat size modules
- Modules are sealed via inflatable seals to the work volume
- Trash and small items are brought in/out of the work volume via containers that mate with the gloveports

SYSTEM CHARACTERISTICS (CONT'D)

The sizing of the main Contaminant Removal System (CRS) canister is based on the main Trace Contaminant Control System (TCCS) canister built for the General Purpose Work Station (GPWS.) The sizing calculations provide an estimate of the volume required for trace contaminant removal. More detailed analysis will need to be done to generate a higher fidelity design of the CRS.

The CRS will have to handle many of the same contaminants as the TCCS. The main differences between the two units would be related to the different mission duration and air flow rates of the GPWS and Life Sciences Glovebox. The TCCS was sized for a 30 day mission, to process air flowing at a rate of 1.4 m³/min (50 cfm). The CRS should be sized for a 90 day mission, to process air flowing at a rate of 0.6 m³/min (20 cfm).

Assuming the canisters are of equal length, the cross sectional area was assumed to be directly proportional to air flow rate and mission duration. Based on the assumption above, the CRS is estimated to be 38 cm (15 inches) in diameter, slightly larger than the TCCS, which is 36 cm (14 inches) in diameter. The contents and structure of the CRS and TCCS canisters are assumed to be similar.

Using similar reasoning, the vent CRS canister was calculated to be 17 cm (6.7 inches) in diameter.

It is important to note that the CRS canisters that are part of the Life Sciences Glovebox are different from the CRS canisters in the Habitat Holding Unit and Centrifuge. The canisters will be different because the Glovebox CRS will have a different chemical load than the CRS for the other rack systems.

CONTAMINANT REMOVAL SYSTEM

- Contaminant Removal System (CRS) canisters remove trace contaminants from air
- Estimated 90% efficiency rating
- Main CRS:
 - Processes all air exiting from work volume and Habitats
 - Sized for .6 m³/min (20 cfm) air flow for 90 day mission
 - Cross sectional area = 1,130 cm² (175 in²)
- Vent CRS Sizing:
 - Processes all air that will be vented to the cabin
 - Sized for 1500 cc/s (3 cfm) for 90 day mission
 - Cross sectional area = 225 cm² (35 in²)
- Both beds have a depth of 58 cm (23"): 2.5 cm (1") LiOH, 15 cm (5.9") charcoal, 8 cm (3.1") Purafil, 15 cm (6") HEPA, and 18 cm (7") for spring, container, and structure
- Designed to remove ammonia, glutaraldehyde, toluene, acetic acid, methanol, acetone, formaldehyde
- Glovebox CRS is different from CRS for Holding Unit and Centrifuge

SYSTEM CHARACTERISTICS (CONT'D)

The Life Sciences Glovebox is designed to collect and store all waste matter generated during operations. Vapors from the Habitats and work volume will contain dissolved contaminants. The vapors will be condensed in an air-to-water heat exchanger, and removed via a centrifugal phase separator. Condensate will be stored in a bladder, which can be either plumbed directly to the PMMS system for drainage, or detached and manually moved to a storage area when full. The baseline configuration has the bladder emptying into the PMMS.

Waste matter collected by the vacuum is initially filtered to remove solids. Liquids and vapors pass through the condenser and are removed by the phase separator. The vacuum filter is enclosed in a container. When the container is full, it can be detached and replaced with an empty one.

Trash within the work volume can be removed via the glovebag system outlined earlier.

WASTE MANAGEMENT

- Condenser and phase separator remove vapors from air
- Condensate is stored in a waste storage bladder
- Bladder empties into the PMMS
- Vacuum subsystem handles spills within work volume
- Solids within spills are filtered and stored within the vacuum waste container
- Gas and liquid spills are processed through the condenser, phase separator, and main CRS
- Trash is placed into bags that attach to the gloveports

SYSTEM CHARACTERISTICS (CONT'D)

Estimates of the mass and volume of the major Glovebox components were made. These estimates were based on information from various sources. Items such as the MDM are being built under contract for Freedom, and the estimates in the following table reflect the information for these components available at the time this report was written. Other equipment (such as the phase separator) are modifications of previously flown space flight hardware. Equipment sizes were also based on catalogue information for non-space flight hardware. The size and mass for each of the remaining items were estimates based on engineering judgement and experience.

MASS/VOLUME CHARACTERISTICS

SUBSYSTEM & COMPONENTS	DRY MASS kg (lbm)	VOLUME cm3 (in3)	BASIS
Consumables:			
Waste storage bags	5 (10)	9341 (570)	Rough estimate
HEPA filters	9 (20)	21139 (1290)	Catalogue
CRS Canisters	45 (100)	65712 (4010)	Mod. exist. hrdwr.
Electronics:			
Power Protection Assemblies (PPA)	7 (15)	6719 (410)	Freedom supplied
power electronics	7 (15)	17206 (1050)	Freedom supplied
MDM/EDP	18 (40)	6227 (380)	Freedom supplied
video displays and control panels	23 (50)	15895 (970)	Catalogue
RF receiver/demodulators	7 (15)	3605 (220)	Mod. exist. hrdwr.
mini-gas chromatograph	5 (10)	13765 (840)	Catalogue
data storage	2 (5)	23597 (1440)	Rough estimate
Thermal Control:			
water/water heat exchangers	11 (25)	9504 (580)	Freedom supplied
water/air heat exchangers	5 (10)	7046 (430)	Catalogue
cold plates	11 (25)	7866 (480)	Freedom supplied

SYSTEM CHARACTERISTICS (CONT'D)

Before calculating the total mass and volume of the components, a 25% design contingency was factored into the total.

The total mass of the Glovebox system, including the rack but not any attached equipment or habitats, is greater than the allowable launch mass for unreinforced payload racks. This requires the Glovebox rack to be structurally reinforced to withstand launch loading conditions. The total volume of all the internal components of the Glovebox, except for the rack structure, is approximately 2/3 of the available internal rack envelope.

MASS/VOLUME CHARACTERISTICS

SUBSYSTEM & COMPONENTS	DRY MASS kg (lbm)	VOLUME cm3 (in3)	BASIS
Power mechanisms:			
pumps	7 (15)	5899 (360)	Catalogue
fans	2 (5)	2294 (140)	Catalogue
lights	2 (5)	9504 (580)	Rough estimate
phase separators	9 (20)	10160 (620)	Mod. exist. hrdwr.
Structure:			
rack mass	61 (135)	- -	Freedom supplied
substructure mass & work volume	61 (135)	469981 (28680)	Rough estimate
plumbing, ducts, and insulation	55 (120)	66040 (4030)	Rough estimate
cables	9 (20)	655 (40)	Rough estimate
Subtotal	361 (795)	772158 (47120)	
25% Design Contingency	90 (200)	193040 (11780)	Rough estimate
Totals:	452 (995) ¹	965198 (58900) ²	(No Habitats or LSE)

(1) 113% of allowable launch mass without additional support

(2) 65% of estimated 90,700 in³ of internal rack volume

SYSTEM CHARACTERISTICS (CONT'D)

The adjacent chart summarizes the electrical power required by the Glovebox. The estimates are based on Freedom supplied information, existing space flight hardware, estimates, calculations, and catalogues. For each component, the method of thermal rejection is listed. For electronics items, coolant circulating through a cold plate provides the heat sink.

The most power the Glovebox will require, not including Habitats or equipment brought into the work volume, is 1435 watts. But during a typical operation, power is reduced to 1320 watts. These estimates include a 25% design contingency.

POWER CHARACTERISTICS

MAJOR SUBSYSTEM & COMPONENTS	OPERATIONAL POWER (W)	THERMAL REJECTION
<hr/>		
Electronics:		
Power Protection Assemblies(PPA)	45	coolant (via cold plate)
power electronics	150	coolant (via cold plate)
MDM/EDP	85	coolant (via cold plate)
video displays	170	coolant (via cold plate)
RF receiver/demodulator	25	cabin and avionics air
mini-gas chromatograph	30	avionics air
Powered mechanisms:		
pumps	120	coolant
fans	365	coolant, cabin air
lights	60	coolant, cabin air
phase separators	60	coolant, avionics air
Other:	40	coolant, avionics air, cabin air

- Peak Power: 1435 W (including 25% design contingency, not including Habitats or LSE)
- Nominal Power: 1320 W (including 25% design contingency, not including Habitats or LSE)

SYSTEM CHARACTERISTICS (CONT'D)

The various filters and CRS canisters used in the Glovebox will need to be periodically changed. The CRS canisters are sized for replacement every 90 days. Experience with ground hardware has shown that HEPA filters need to be replaced not more than once per year. Regular use of the Glovebox will also generate large amounts of trash from operations. The following table summarizes the servicing frequency required of the different consumables, and the mass and volume of the consumables. The volume stated for the trash is an noncompacted volume. If a compactor were available onboard, this volume would be markedly reduced.

Since HEPA filters need to be changed only once a year, the stated servicing frequency is 1/4 per 90 days. However, the listed mass and volume are the amounts that would be required during one entire year.

CONSUMABLES

Over a 90 day period, the following items would be removed from the LSG:

ITEM	SERVICING/90 DAYS	DRY MASS lbm (kg)	VOLUME in ³ (m ³)
Main Contaminant Removal Subsystem (CRS)	1	85 (39)	3390 (0.06)
Vent CRS	1	15 (7)	620 (0.01)
Filters:	1/4	15 (7)	1300 (0.02)
- HEPA			
- coarse			
Trash:		255 (116)	32941 (0.54)*
- wipes & absorbent pads			
- gloves			
- waste tray liners			
- specimen tissue			
- other			
Vacuum waste		50 (23)	1490 (0.02)

* noncompacted volume

HABITAT INTERFACES

The Life Sciences Glovebox and Modular Habitats comprise the Life Sciences Glovebox System. The Glovebox provides thermal, power, data, and life support resources to sustain specimens for a period of 24 hours. Since the Habitats will contain sufficient food, water, and nutrients to sustain the specimens for 24 hours, the Glovebox needs to provide only conditioned air and coolant fluid to maintain ECLS (environmental control life support) for the specimens. Each animal Habitat must be provided with approximately 500 cc/s (1 cfm) of air that is filtered and chilled down to the desired set point temperature.

Video and other data transmissions from the Habitats must be received by the Glovebox and processed for handling by the Space Station Freedom DMS (Data Management System). Electrical power must be supplied in the form of 28 VDC.

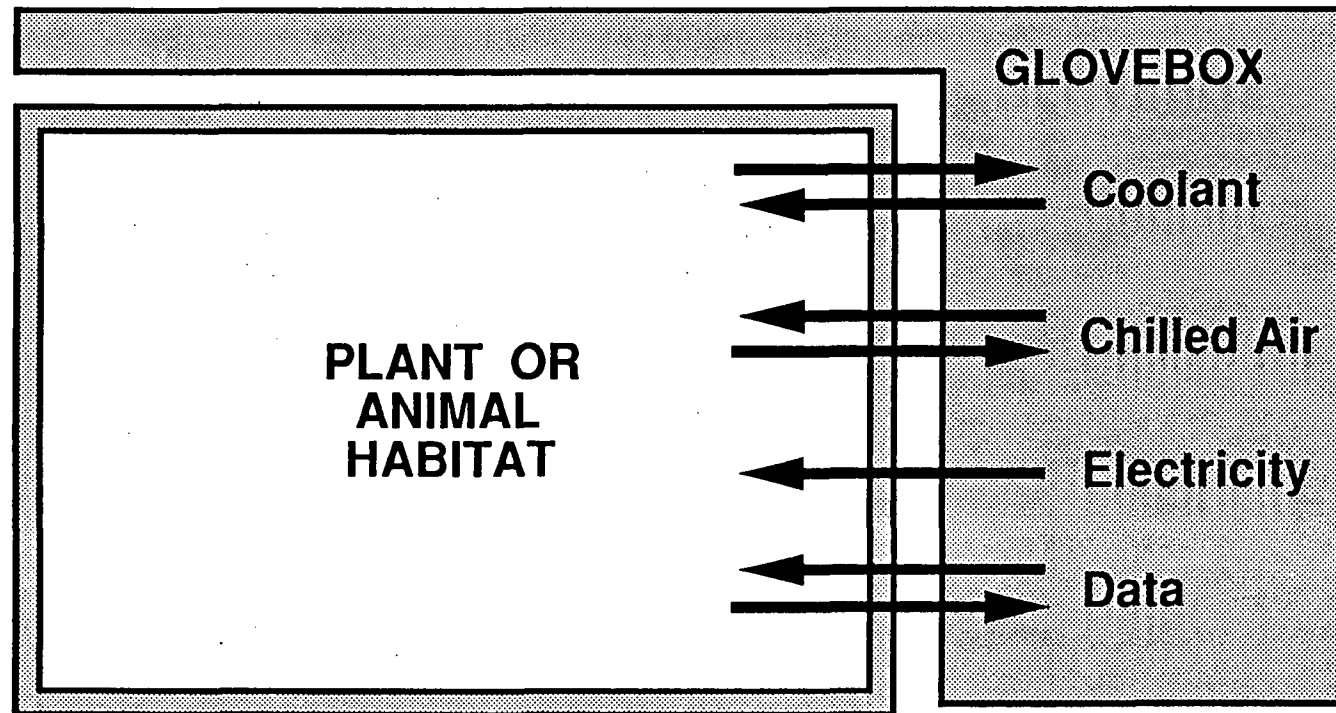
HABITAT INTERFACES

- Maintain specimen ECLS within Habitats for 24 hours except gases and nutrients for the plants, and water for the animals
- Chilled air and coolant water for Habitat thermal control
- Approximately 500 cc/s (1 cfm) of air flow per animal Habitat
- Transmission and processing of video and other data signals
- Electrical power

HABITAT INTERFACE DIAGRAM

The following is a schematic of the interface between the Life Sciences Glovebox and Modular Habitats.

HABITAT INTERFACE DIAGRAM



Animal Habitats contain a minimum 24 hour
reservoir of food and water

FREEDOM INTERFACES

When in use, Glovebox operations will require Freedom resources for the Life Sciences Glovebox (LSG), Habitats attached to the Glovebox, and lab support equipment (LSE) being used in the work volume. The following chart summarizes the amount of power consumed, thermal load, and data input and output expected from three different sets of equipment.

The Glovebox could use three separate output video channels to simultaneously monitor the work volume and Habitats, and to support video microscopy. However, if the number of channels is limited, the Glovebox can limit its use to one output video channel by multiplexing the various channels. One input video channel is required to support telescience operations.

FREEDOM INTERFACES

Utility	LSG	Habitats	LSE	Total
POWER CONSUMPTION				
Peak Power (W)	1435	0-610	0-500	1435 - 2545
Nominal Power (W)	1320	0-370	0-200	1320 - 1890
NOMINAL HEAT REJECTION				
4°C Coolant Loop (W)	1045	0-230	0-150	1045 - 1425
Avionics Air (W)	150	0	0	150
Cabin Air (W)	125	0-140	0-50	125 - 315
DATA				
Engineering (Kbps)	5.4	0-0.4	0	5.4 - 5.8
Science	0	0-2.2 Mbps	0-1 Kbps	0 - 2.22 MBPS
Video	1 output 1 input	1 output	1 output	1 - 3 outputs 1 input

FREEDOM INTERFACES

In addition to power, data, and cooling, the Glovebox will rely on equipment provided by Freedom. Equipment used inside the Glovebox will either be Laboratory Support Equipment or equipment custom designed for an experiment. The Glovebox uses modular carriers (equipment modules) to bring equipment in and out of the work volume. To reduce bioisolation concerns, the equipment should be permanently housed inside these modules to avoid exposing this equipment to the cabin environment. This affects the Freedom stowage volume for these items, and how the equipment interfaces with other rack systems such as the Maintenance Work Station.

The Process Materials Management System (PMMS) will be used by the Glovebox to handle solid and liquid wastes. The Glovebox has the capacity to store wastes for short periods of time (several days) but needs the PMMS for final processing and/or storage. Containers of solid waste can be manually carried from the Glovebox to the appropriate stowage area. Liquid waste containers can be drained directly to the PMMS, or manually carried to the appropriate area for disposal.

The PMMS must provide a vacuum system for users. However, it is likely that this vacuum will be unsuitable for Glovebox clean-up, hence requiring the Glovebox to provide its own system. The baseline Glovebox design incorporates its own vacuum system.

The interfaces to the Freedom caution/warning system, fire suppression/detection, and PMMS portable glovebox have not been defined. More information must be gathered before these interfaces can be specified.

FREEDOM INTERFACES

- Laboratory Support Equipment and experiment specific equipment:
 - Items will be transported to/from the Glovebox within equipment modules that interface with the work volume in a method similar to habitats.
 - Items must be stowed within these equipment modules at all times
- PMMS
 - Waste Management: solid and liquid waste disposal
 - Ultrapure Water System: ultrapure water for clean up, experiment use, and habitat resupply
 - Fluid Management System: compressed nitrogen
- Vacuum System: if available, it will be used in lieu of Glovebox vacuum system for clean-up
- PMMS Portable Glovebox: TBD interface
- Caution/Warning system: TBD interface
- Fire detection/suppression system: TBD interfaces

MAINTENANCE

Equipment items that need to be accessed regularly for change out or maintenance were positioned close to the front or rear of the rack. The rack front is ideal for accessing equipment. However, the work volume, Habitat plug-in panels, and vents occupy the majority of frontal area, so the amount of equipment that can be accessed from the front is limited. Only items that needed to be changed more frequently than every 90 days were located at the front of the rack. These items include the vacuum waste container and liquid waste storage bladder. For repair and maintenance of other equipment, the Habitat plug-in panels can be removed, providing greater access to the interior of the rack.

Items requiring less frequent change out were placed in the rear of the rack. They are accessible from removable panels in the back of the rack, but the entire rack must be pivoted into the aisle to get to these panels. The CRS canisters can be replaced from the rear once these panels are removed.

To reduce maintenance, redundant components are included in a number of the subsystems. These include redundant fans, pumps, motors, and sensors. The MDM/EDP is assumed to include redundant components within itself.

MAINTENANCE

- Expendables accessible from the front of the rack:
 - Vacuum waste container
 - Liquid waste storage bladder
- Rack front has removable panels to access:
 - Fluid lines and air ducts
 - Pumps
 - Filters
 - Phase separators and motors
 - Electronic components
- Rack back has removable doors to access the CRS canisters
- Redundant components:
 - Coolant pumps
 - Sensors
 - Fans
 - Phase separator motors
 - Redundancy is assumed to be built into the MDM/EDP

OPERATIONS

Glovebox operations will require extensive amounts of crew time. A Spacelab SLS-2 vestibular experiment calls for the dissection of 5 rats. Ground based studies estimate it will require 5.43 man-hours of continuous crew time to perform these dissections. Some operational times can be reduced by more than half if another crew member is available to assist. Other operations may require more than one crew member to perform. This is typical of dissections, since they can proceed more smoothly and efficiently when two people are working together. Besides power, data, and PMMS availability, crew time will be an important parameter in determining Glovebox scheduling and the level of scientific quality derived from life science experiments.

The Glovebox is also expected to support specimen chamber servicing operations. The baseline Service Unit concept necessitates the use of the Glovebox to transfer clean and dirty specimen chambers between Modular Habitats and wash modules. The unrestrained squirrel monkey specimen chamber is likely to be the largest item that will be within the work volume, and drives the size of the work area. Simple clean-ups of plant chambers, requiring only manually wiping the surfaces with a disinfectant, can be performed at the Glovebox.

Based on the need to perform science and servicing operations within the Glovebox, it is expected that it will be in use almost every day.

OPERATIONS

- Glovebox operations will be limited by available crew time
- Life Sciences Glovebox and Specimen Chamber Service Unit scheduling are interdependent - driven by baseline Service Unit design
- Daily usage of the Glovebox is expected
- Some procedures within the Glovebox, e.g. animal dissection, may take 5-6 hours of continuous crew time

TRADEOFFS

To develop the Glovebox baseline design, a number of tradeoff studies were performed to evaluate the different design options. The options and their respective merits are covered in the following pages.

The tradeoffs concentrated on the design of the work volume and support for the Habitats. In each study, several options are reviewed. The option is listed at the top of each column. Advantages of the option are notated by a "+", and disadvantages are preceded by a "-". Items that are neither advantageous or disadvantageous are preceded by a "o". The "+, -, o" notations are qualitative and should not be tallied to determine quantitative measures of merit.

Based on the relative merits of each trade-off, a selection was made. This selection is listed on the bottom of each tradeoff, within the box labelled "current choice." The label indicates that this is the present baseline option selected. However, information is still being gathered and the choice could change after future studies are completed.

TRADEOFFS

The following is a list of tradeoffs made during this study

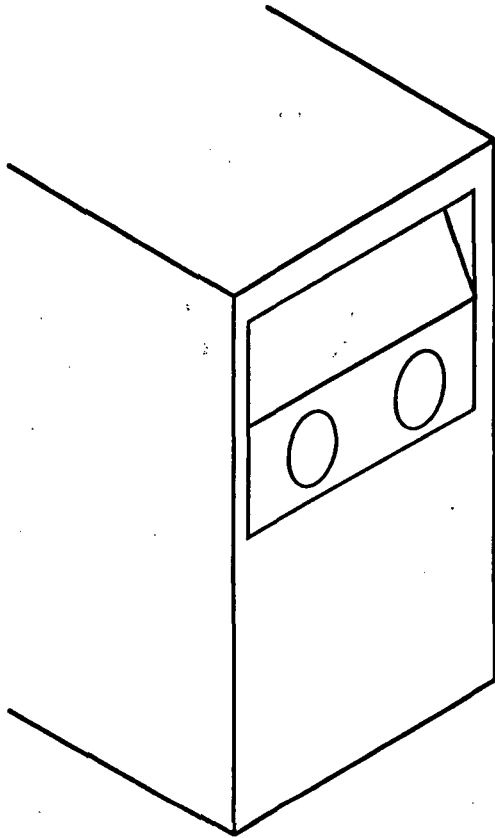
- Work volume configuration
- Work volume deployment
- Work volume shape
- Work volume air flow
- Habitat ECLS
- Habitat accommodation
- Habitat door interface

TRADEOFFS (CONT'D)

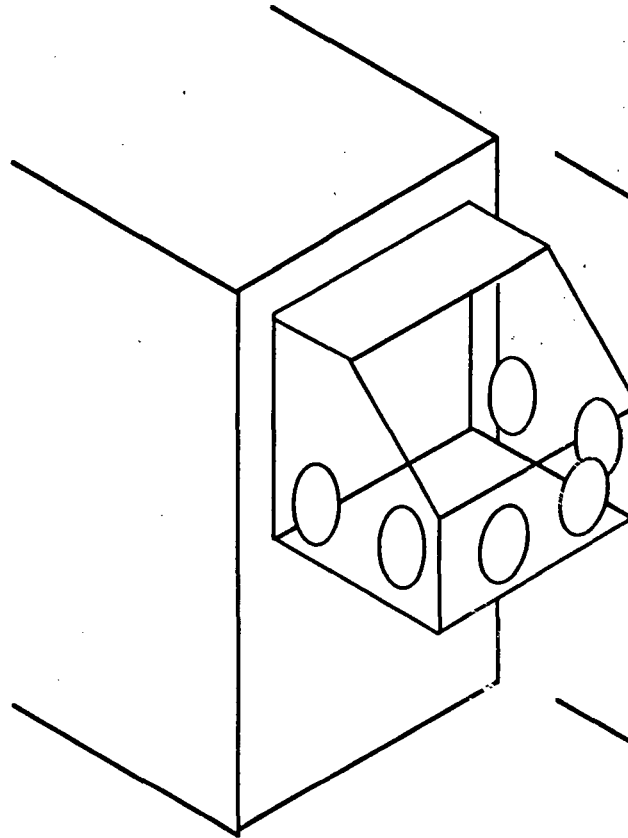
The work volume of the Glovebox must be designed to facilitate crew operations. This involves many different issues, including crew accommodations, volume, cleanability, reliability, and safety. Three possible work volume configurations were reviewed. A fixed work volume could be permanently mounted to the rack and confined to fit completely within the rack envelope. A movable rigid work volume can be deployed into the aisle such that it extends outside of the rack envelope. A collapsible work volume also deploys into the aisle for operations like the rigid work volume. However, the two differ in that the collapsible volume folds up and stows without occupying much volume when not in use.

WORK VOLUME CONFIGURATIONS

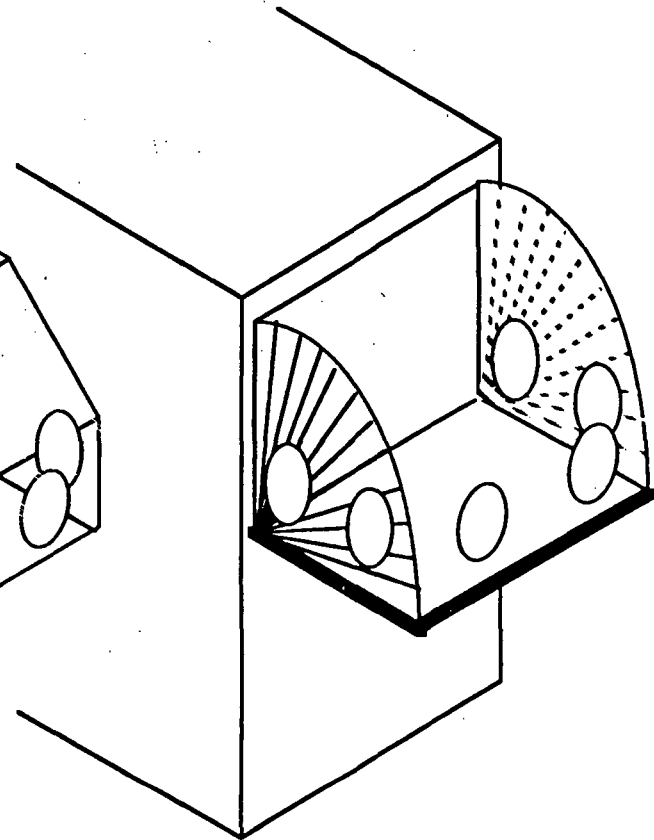
**FIXED
WORK VOLUME**



**MOVABLE RIGID
WORK VOLUME**



**COLLAPSIBLE
WORK VOLUME**



TRADEOFFS (CONT'D)

The requirements to accommodate 2 pairs of hands and 2 Squirrel Monkey Habitats proved to be the primary design drivers. There is insufficient room at the front of a rack to accommodate two users working side by side. Moreover, two squirrel monkey Habitats are too large to fit within a rack that also contains all of the necessary Glovebox subsystems (filters, fans, etc.) For these reasons, the fixed work volume was disqualified.

Both the movable and collapsible work volumes have no problem accommodating two users and two Habitats. However, the collapsible work volume necessitates the use of a flexible material, which is vulnerable to punctures and tears, is difficult to clean, and distorts viewing. The rigid work volume is without these problems, thus it is the choice selected.

The movable rigid work volume might need a waiver to allow deployment into the cabin aisle. Aisle clearance and time for work volume storage during emergency situations may not meet Freedom requirements.

WORK VOLUME CONFIGURATION

Fixed Work Volume	Movable Rigid Work Volume	Collapsible Work Volume
- Cannot accommodate 2 pairs of hands	+ Accommodates at least 2 pairs of hands	+ Accommodates at least 2 pairs of hands
- Cannot accommodate 2 large habitats	+ Accommodates 2 large habitats	+ Accommodates 2 large habitats
+ High reliability, no maintenance	- Medium reliability, some maintenance	- Potential problems with leaks, tears, punctures
+ No intrusion into aisle	- Intrudes into aisle	- Intrudes into aisle
+ No distortion	+ No distortion	- Visual distortion
+ Easy to clean	+ Easy to clean	- Difficult to clean
+ No movable parts	- Movable parts required	- Movable parts required
- Empty work volume occupies rack volume	- Empty work volume must be stowed	+ No empty work volume to stow
+ No waiver required	- May require waiver	- May require waiver

Current Choice: The movable work volume is the simplest and most practical way to accommodate 2 pairs of hands

TRADEOFFS (CONT'D)

There are two means to deploy the work volume into the aisle: sliding and pivoting. Multiple sliders are used on the Spacelab General Purpose Work Station (GPWS) to bring the work volume into the aisle. Experience with the GPWS showed that the sliders were plagued by alignment problems. To avoid those complications, the Life Sciences Glovebox uses hinges to deploy the work volume.

WORK VOLUME DEPLOYMENT

Slide-out

- Potential problems with alignment
- Depth of work volume limited to depth of rack
- + Design experience from GPWS

Pivot

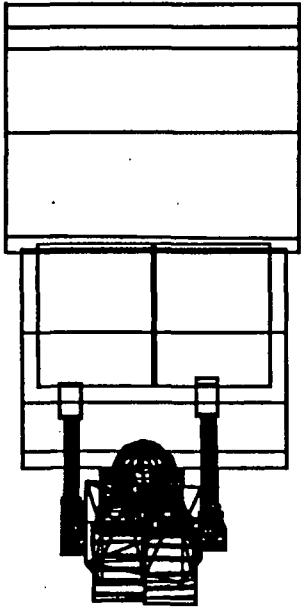
- + No alignment problems
- + Depth of work volume limited to height of rack
- Untested in glovebox application

Current Choice: To avoid potential alignment problems associated with mounting the work volume on sliders, the work volume was designed to pivot out from the rack.

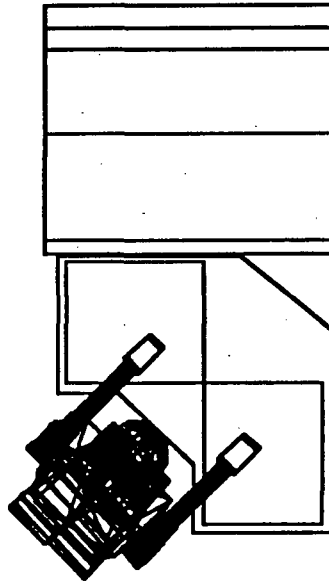
TRADEOFFS (CONT'D)

The shape of the Glovebox work volume is critical in facilitating operations. The work volume must accommodate two simultaneous users, 2 Modular Habitats, and have enough work volume and work surface area to perform complex operations such as rat dissections. To meet these requirements, three different work volume designs were identified. These were evaluated using computer models and full scale mockups.

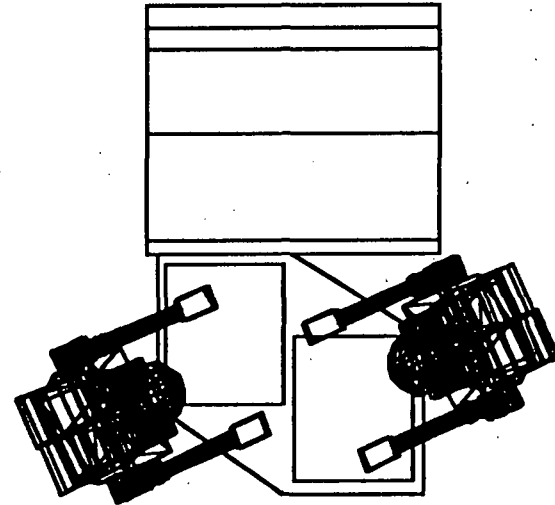
TRADEOFFS (CONT'D)



**TILT DOWN
WORK VOLUME**



**HUMAN FACTORS
WORK VOLUME**



**MULTI-FACETED
WORK VOLUME**

TRADEOFFS (CONT'D)

The tilt-down work volume is shaped to make full use of the available volume that is swept out when it pivots out from the rack, approximating the shape of a quarter section of a cylinder. It provides the best overall accommodations for two users, and the largest internal work space, hence it was selected as the baseline design for the Glovebox. The main problem with this design is that the work surface is occupied by the doors leading to the Habitats. Operations are slowed because work and equipment must be removed from the doors if the Habitats need to be accessed.

This is less of a problem in the human factors work volume. Large, uninterrupted work surfaces are available directly in front of the primary user because the doors are offset to the side. This design also affords excellent ergonomic considerations for the primary user. However, the internal volume available is small and constrains the manipulation of large pieces of equipment.

The multi-faceted work volume allows two users to work opposite each other on one operation, or two separate ones. However, it has few other outstanding advantages over the other designs.

Current work in this area is concentrating on developing new designs, and improving the tilt down and human factors work volumes.

WORK VOLUME SHAPE

Tilt-down Work Volume	Human Factors Work Volume	Multi-faceted Work Volume
<ul style="list-style-type: none"> + Good visual and physical access for primary user + Easy to work with large objects - No large uninterrupted work area o Moderate visual and physical access for secondary user + Has 6 gloveports - Users protrude into the aisle beyond the envelope of the work volume 	<ul style="list-style-type: none"> + Excellent visual and physical access for primary user - Very difficult to work with large objects + Large, uninterrupted work area is available - Poor visual and physical access for secondary user o Has 4 gloveports + Users do not protrude into the aisle beyond the envelope of the work volume 	<ul style="list-style-type: none"> o Moderate visual and physical access for primary user + Easy to work with large objects - No large uninterrupted work area o Moderate visual and physical access for secondary user + Has 5 gloveports + Users do not protrude into the aisle beyond the envelope of the work volume + One operator can wedge him/herself between the rack and the work volume
<div> <p>Current Choice: The tilt-down work volume offers the best overall user accommodations</p> </div>		

TRADEOFFS (CONT'D)

Air flow provides two functions: maintaining cleanliness via waste entrainment, and eliminating pockets of dead air. High air flow does a good job of capturing particles, but at a cost of large, noisy, power consuming blowers. Lower air flows are poor at particle collection, but require smaller, more efficient and less noisy fans. Either flow scheme should be sufficient to provide air for life support.

The Glovebox relies on physical barriers and negative pressure for particulate containment. Although air entrainment is desirable, it is not necessary. Without the need to entrain particles, the low air flow scheme was selected.

WORK VOLUME AIR FLOW

High Air Flow

Low Air Flow

- | | |
|--|--|
| + Good entrainment of particles | - Poor entrainment of particles |
| + Faster decontamination of recirculated air | - Slow decontamination of recirculated air |
| - Large, high power consuming blowers required | + Small, low power consuming blowers required |
| - Large blowers generate much waste heat, noise, and vibration | + Small blowers generate little waste heat, noise, and vibration |
| - Glovebox will act as a processor of cabin air | |
| - May dry out samples | |

Current Choice: Air flow is low to reduce power to and noise from the blowers.

TRADEOFFS (CONT'D)

Separate ECLS loops provide the best approach to preventing cross-contamination between the Habitat and work volume contents. However, separate air loops require duplicate blowers, ducting, valves, filters, CRS canisters, condensers, and phase separators. All of this results in mass, volume, and power penalties. The baseline Glovebox concept has insufficient volume for two separate ECLS loops, so the two are combined. Habitats and work volume have separate input air streams, but all contaminated air passes through the same processing hardware.

HABITAT ECLS

Separate Loop

- + Work volume and Habitat ECLS are separate and independent
- + Habitats can remain at the Glovebox during times when the work volume is being decontaminated or vacuumed
- Additional ducting and ECLS components (condenser, CRS canister, HEPA filters, fans) are required
- Impossible to avoid mixing Habitat and work volume air when door to the Habitat is open to the work volume

Combined Loop

- Work volume air flow system must be operating to maintain ECLS support
- If there is a spill inside the work volume, air flow is recirculated and Habitats must be removed
- + No extra hardware required to maintain Habitat ECLS support
- Waste air from Habitats is mixed with waste air from the work volume and recirculated into the work volume

Current Choice: Ideally, the Habitat ECLS should be a separate loop from the air flow loop of the work volume. However, because of limited available volume, the habitat ECLS and work volume air loops must be combined.

TRADEOFFS (CONT'D)

The Glovebox must accommodate two habitats of any size. It must provide access to these habitats without allowing cross-contamination between the cabin and work volume environments. There are two methods to interface the habitats with the Glovebox: direct mounting and air locks.

Air locks would incorporate a double door system whereby equipment and habitats would be placed inside an intermediate chamber prior to transfer between the Glovebox and the cabin. Once items are placed inside the chamber, the air inside would be purged and scrubbed prior to it being opened again. Such a system would incur a large volume penalty. The space for the air lock chamber itself would need to be as large as two Unrestrained Squirrel Monkey Habitats. Furthermore, additional blowers, filters, valves, and other equipment would be required to process the air. Lastly, air lock surfaces and the external surfaces of all equipment brought into the work volume would need to be manually cleaned each time the airlock is used, demanding extensive amounts of crew time.

Attaching the habitats directly to the Glovebox involves sealing the two systems together at the door interface. Because the seals and habitat itself provide the bioisolation barriers, there is no volume penalty, and the habitats are not restricted in size as long as they interface with the Glovebox in the desired manner. The major drawback of this method is that it requires all equipment to interface with the Glovebox via modules. This means that laboratory and experiment support equipment must be placed in containers that interface with the Glovebox in the same manner as habitats.

HABITAT ACCOMMODATION

Direct Mounting of Habitats to the Work Volume

Habitats Access via an Air Lock

- | | |
|--|--|
| <ul style="list-style-type: none">+ No restriction on size of habitats as long as they have the same door interface+ No additional volume must be allotted to accommodate the habitats+ Minimal crew time required for mounting and accessing the habitats+ No need to clean up exterior of habitat- All large equipment must interface with the Glovebox via habitat-like equipment modules- Relies on potentially unreliable sealing of the habitat to the work volume to maintain bioisolation | <ul style="list-style-type: none">- All Habitats and equipment must fit within the dimensions of the air lock- Large volume required for air locks- Time and power are required for decontaminating the air and surfaces inside the air lock prior to opening it up- All equipment and habitats must be cleaned and decontaminated prior to removal from the Glovebox+ Large and small equipment may pass through the air lock+ Bioisolation depends on seals <u>and</u> filtering of the air |
|--|--|

Current Choice: Direct mounting of the habitats to the work volume is preferred because of the lower crew time and rack space required to access equipment and habitats.

TRADEOFFS (CONT'D)

Habitats can be mounted anywhere on the outside of the work volume. The location of the habitat defines the placement of the habitat/Glovebox door interface. Mounting habitats underneath the work volume has the advantage of locating the plug-in panel on the front of the rack. This allows the habitats to be slid underneath the work volume to attach to the interface panel. But this also requires the doors to be in the bottom surface of the work volume. This surface is also the primary work space for operations. Having doors located there obstructs the work space and interrupts operations whenever a door needs to be opened.

Placing habitats on the side of the work volume eliminates the door obstruction problem. However, tests with full scale mockups showed that physical and visual access into side mounted habitats are extremely limited.

The baseline choice was to access the habitats through the bottom surface. However, after performing trial experiment protocols inside a mockup of the baseline Glovebox design, scientists and engineers agreed that the doors were very cumbersome to use. Work constantly needed to be shifted off of door surfaces to open them. This slowed operations and made them tedious to perform. Because of these problems, studies of Habitat accessing schemes are continuing.

DOOR INTERFACE TRADEOFF

Access thru Bottom Work Volume Surface

Access Through a Different Surface

- | | |
|---|--|
| + Good access to interior of habitat | - Poor access to interior of habitat |
| + Plug in interface can be rack mounted | - Plug in interface cannot be rack mounted |
| - Primary work surface contains access door | + Primary work surface free of access door |

Current Choice: To facilitate Glovebox design and access to the habitats, the access door is located on the horizontal surface of the work volume.

However, experience with full scale mockups shows that existing door concepts are awkward to use. New concepts must be developed.

REQUIREMENTS NOT MET

The current baseline Glovebox design meets most of the science and functional requirements. However, there are two requirements that are not met. The Phase B Specification requires that all hardware maintain two levels of bioisolation at all times, including the filter change out. The Glovebox design violates that requirement for brief periods of time. During CRS exchanges, small areas of contaminated surfaces are exposed to the cabin environment until a double walled bag can be placed around it.

The Glovebox is currently not designed to accommodate operations with radioactive materials. More research in the areas of shielding, handling, and disposal of radioactive materials must be performed.

REQUIREMENTS NOT MET

The following requirements have not been met by the current concept:

- 2 levels of bioisolation maintained during filter change out
- Handling of radioactive materials

FURTHER STUDY

Whether or not the noise and vibration limitation requirements have been met cannot be satisfactorily determined until actual hardware is built. However, the baseline Glovebox selected a low air flow regime to reduce the size and power required by the fans. These fans should not exceed the noise and vibration limits.

The satisfaction of several other requirements is a function of hardware design and crew operations. This includes all requirements involving maintenance, bioisolation, clean-up, and glove change. For example, the Glovebox work volume requirements state that cleaning should not take longer than 30 minutes after a typical operation. Meeting that requirement is partially dependent on the design of the work volume. The baseline design incorporates 2 cm (1 inch) radius internal corners, visibility of all areas, and no crevices. These features facilitate clean-up. However, the actual procedure and materials for clean-up will also play a major role in meeting the 30 minute time limit.

Several Freedom interfaces are not defined in this report because of insufficient information. More investigations must be done to understand the Freedom interface requirements for the PMMS portable glovebox and fire detection and suppression system.

C-1

FURTHER STUDY

- Hardware tests are required to determine if the vibration & acoustic noise limitation requirements are met
- Satisfaction of the following requirements partially depends upon the development of suitable operations:
 - Bioisolation
 - Cleanability and sanitization
 - Maintenance
 - Glove change
- Gather more information describing the appropriate interfaces for the
 - PMMS portable glovebox
 - Fire detection and suppression system
 - Caution/warning system

FURTHER STUDY (CONT'D)

Although many aspects of the Glovebox design have been covered in this study, there are some areas that deserve more attention. A user volume study must be performed to determine the appropriate Glovebox work volume. It is also necessary to determine if a waiver authority is required to deploy the work volume into the aisle. Obtaining a waiver would probably depend on the ability of the work volume to be folded back into the rack during emergency situations. This would include detaching Habitats and removing them from the Glovebox.

Even though extensive work has been done in the area of human factors accommodations, more work needs to be done. More trial protocols must be performed inside the Glovebox to better understand one and two person operations. Furthermore, the KC-135 or a neutral buoyancy tank must be used to study accommodations for crew working in a weightless environment. Lastly, the issue of accessing the Habitats must be analyzed in more detail. Other options related to the location and design of the doors need to be examined to facilitate operations.

FURTHER STUDY (CONT'D)

Work Volume:

- Determine minimum volume required for operations
- Acquire waiver authority (if needed) to deploy work volume into aisle
- Identify methods to facilitate work volume stowage to meet the safety requirements

Human Factors:

- Evaluate interface for 1 and 2 person operations
- Evaluate interface for 0-g and 1-g environments
- Evaluate visibility and physical access into the habitats
- Determine optimal location and configuration of habitat doors

FURTHER STUDY (CONT'D)

Designing the Glovebox to accommodate radioactive materials requires additional research. All radioactive materials that may be used inside the Glovebox must be identified. Since work with radioactive substances is difficult and hazardous, substitutes for radioactives must be identified wherever feasible. For the radioisotopes that must be used, a study must be performed of how they would be used, how they could be safely handled inside the Glovebox, and how their use and storage would affect the rest of Freedom.

Microscopy is another operation that poses problems for the Glovebox. The Glovebox must allow viewing with the microscope while maintaining full enclosure. The latter requirement prevents normal microscopy viewing methods, since conventional ocular pieces cannot be used through the work volume windows. Video microscopy and modified ocular pieces are other potential methods that could be used. However, more research into this area is required.

The Glovebox baseline design requires that all equipment to be used inside the work volume be stowed inside equipment modules. The dimensions of these modules, which have yet to be determined, pose an additional constraint on the design of these items. Furthermore, this stowage requirement increases the volume required to store the items when not in use. Lastly, other rack systems such as the Maintenance Work Station may need to interface with some of these items, and would need a special interface to these equipment modules.

FURTHER STUDY (CONT'D)

Radioisotopes

- Identify special tools and techniques to be used with radioisotopes
- Evaluate impact of radioisotopes on the rest of the Centrifuge Facility and Freedom
- Identify suitable substitutes for radioisotopes where possible

Laboratory support and experiment specific equipment:

- Evaluate different microscope/Glovebox interfaces
- Determine the impact of permanently stowing equipment within equipment modules

FURTHER STUDY (CONT'D)

Bioisolation is an important requirement that affects the design of the entire Facility. As related to Glovebox design, there have been a few weaknesses in the design that require more study. The sealing of the habitats and other modules to the Glovebox is one potential weak point. Inflatable seals will require some development and testing before there can be full confidence in them. Techniques for safely changing filters must be identified and tested. The air ducting can be the site of microorganism growth, hence methods for decontaminating must be defined. The same can be said for decontamination and sterilization of the work volume.

The last two areas identified are operations related. However, the goal of an operation can be met only if the operation is performed correctly. The Glovebox design must be optimized to limit the reliance on operations to meet specific requirements. The design shall also facilitate operations wherever possible.

FURTHER STUDY (CONT'D)

Bioisolation:

- Refine method to seal Habitats and equipment modules to the work volume
- Develop techniques for change-out of filters and CRS canisters
- Identify method for periodic decontamination of the air flow system
- Identify standardized procedures for decontamination and sterilization of the work volume
- Optimize designs to limit the reliance on operational procedures for bioisolation

TECHNOLOGY DEVELOPMENT

In general, the Glovebox needs little technology development to meet specified requirements. The few necessary development areas are not viewed as major obstacles. One technology in question is the glove change technique. The basic method is satisfactory in that gloves can be changed quickly without violating bioisolation. However, this method requires the use of a large, manually driven tool to push the new glove in and force the old one out. This tool needs to be revised for zero-g operations.

There are also technologies in use that may be useful in the Glovebox. For example, electrostatic precipitators are commonly used in clean rooms to maintain low particle counts in the air. This technology should be examined for use inside the Glovebox to capture and control airborne contaminants.

TECHNOLOGY DEVELOPMENT

- Evaluate technologies such as electrostatic precipitation that may facilitate decontamination and waste collection
- Improve glove change method to reduce crew time and effort required

SUMMARY

Most of the requirements for the Life Sciences Glovebox can be met with this current design. This design requires the full use of the volume inside a 74.5 inch rack. Even with this volume, the work volume must be deployed into the aisle to meet the 2 user and 2 habitat requirements. The baseline design reflects the tilt down configuration of the work volume with bottom mounted habitats. However, other Habitat accommodation and work volume configurations were developed and deserve further consideration.

Many of the Glovebox requirements (e.g. cleanability, bioisolation) cannot be satisfied completely by hardware design. Designs can facilitate meeting these requirements, but these requirements are also partially dependent on operations. Many of these operations have not been defined or require further development. Many Glovebox maintenance procedures may require special measures to ensure bioisolation is maintained. Sealing the Habitats to the Glovebox is also a bioisolation concern that merits further investigation.

SUMMARY

Findings of the Glovebox study:

- Most primary science and functional requirements are met with this concept
- Satisfaction of the requirements will require full use of the internal volume of a rack
- Accommodating 2 users and 2 habitats requires deploying the work volume into the cabin aisle
- Numerous ways to accommodate the users have been identified
- Satisfaction of the requirements depends on hardware and operations
- Glovebox operations and emergency procedures require further development
- Habitat interfacing and Glovebox maintenance are the weak links in bioisolation

APPENDIX

BACK OF SUMMARY CHART

APPENDIX

- RAT NECROPSY REFERENCE PROTOCOL

RAT NECROPSY PROCEDURE

The rat necropsy procedure is included here to illustrate how a typical operation may be performed with this Glovebox design. The procedure is preliminary; the actual protocol followed onboard Freedom may be different. However, it is presented here to highlight the steps that are required to bring specimens and materials in and out of the work volume.

Steps that are designated optional should be performed only if the animal specimen chamber needs to be serviced at the same time the necropsy is being performed. If no servicing is required, then these steps can be skipped.

RAT NECROPSY PROCEDURE

EXAMPLE GLOVEBOX OPERATION: RAT NECROPSY

1) Glovebox Preparation:

- i) Turn on Glovebox; check contamination detector to determine if Glovebox needs to be decontaminated;**
- ii) Pull down the work volume to the operational position; Visually inspect all internal surfaces for contaminants; decontaminate (wipe down all interior surfaces, recirculate air for 15 minutes) if necessary;**
- iii) Activate Glovebox computer; instruct it to display procedure and checklist for rat necropsy;**
- iv) Check the operational status of all equipment; inspect gloves to see if they are of appropriate size, type (surgical) and integrity; change gloves if required (see Glove Change-out Procedure);**
- v) If necessary, attach a gloveport bag to a gloveport (see Glove Change-out Procedure);**

RAT NECROPSY PROCEDURE (CONT'D)

2) Equipment Set-up:

- i) Remove the equipment module containing the equipment for rat dissection from its storage area ; transport it to the Glovebox; module contains guillotine, blood tubes, fixatives (may require some time to reach work volume temperature), labeled containers, bags for carcasses, rat restraint, wipes, and other TBD equipment;
- ii) Insert the module into one of the two slots (correct mating will inflate seals automatically;)
- iii) Open equipment module (module and work volume doors lift off as one piece;)
- iv) Remove desired items and place within work volume; run through check list on computer of required equipment and materials;
- v) Wipe exposed surfaces of the module door; replace equipment module door; arrange equipment within work volume in desired configuration;

3) (OPTIONAL) Provision of Clean Habitat:

- i) Deflate seals to equipment module; disconnect module and transport it back to its storage area;
- ii) Remove a habitat with an empty, clean specimen chamber from TBD area; transport it to the Glovebox;
- iii) Insert empty habitat into one of the two slots (correct mating will inflate seals automatically;)
- iv) Open empty habitat module (habitat and work volume doors lift off as one piece;) inspect outer surface of specimen chamber and interior of habitat;
- v) Open door to specimen chamber; inspect inner surfaces of the specimen chamber;

RAT NECROPSY PROCEDURE (CONT'D)

4) Provision of Specimens:

- i) Locate appropriate rat habitat at either the Holding Facility or Centrifuge; check the status of the animal(s) that will be examined; remove habitat and transport it to the Glovebox;
- ii) Insert habitat into an open slot (correct mating will inflate seals automatically;)
- iii) Open occupied habitat module (habitat and work volume doors lift off as one piece;) inspect outer surface of specimen chamber and interior of habitat; open door to specimen chamber;

5) (OPTIONAL) Transfer of Animals to Clean Specimen Chamber:

- i) Identify the rats that will not be sacrificed; reach into the specimen chamber and remove one of these rats;
- ii) Transfer the animal to the empty specimen chamber in the clean habitat; continue transferring all animals that will not be sacrificed; close specimen chamber door when all transfers are completed;
- iii) Close door to the clean specimen chamber; wipe down the exposed surfaces of the habitat interior and habitat door; replace the habitat door; deflate seals;
- iv) Remove the clean habitat; transport it to the appropriate holding area (Holding Facility or Centrifuge;)
- v) Retrieve the equipment module used earlier; transport it back to the Glovebox; insert it into the open slot;

RAT NECROPSY PROCEDURE (CONT'D)

6) Necropsy:

- i) Remove first animal to be sacrificed; place in rat restraining unit; wipe down exposed surfaces of habitat door; replace habitat door;
- ii) Remove rat from restraint; collect data (e.g. mass, temperature, etc.); prepare rat for decapitation; decapitate;
- iii) Collect tissue and blood samples; collect data from samples; apply fixative to samples; place samples in appropriate storage containers; place trash in trash bag;
- iv) Repeat steps i-iii for all animals to be sacrificed;
- v) Seal sample containers; place containers within gloveport bag; use heat sealer to seal bag; cut bag; transport bag to appropriate storage areas;
- vi) Seal trash bags; place bags within gloveport bag;

7) Equipment Return:

- i) If the habitat that contained the examined specimen is not to be serviced, return the habitat to the appropriate holding area; or...
- i) If the habitat is to be serviced, follow the procedure outlined in the Specimen Chamber Service Unit Operations Scenario Section for servicing of the dirty specimen chamber;
- ii) Wipe down soiled equipment; remove door to the equipment module; replace equipment;
- iii) Wipe down exposed surfaces of module door; replace door; deflate seals; return equipment module to storage;

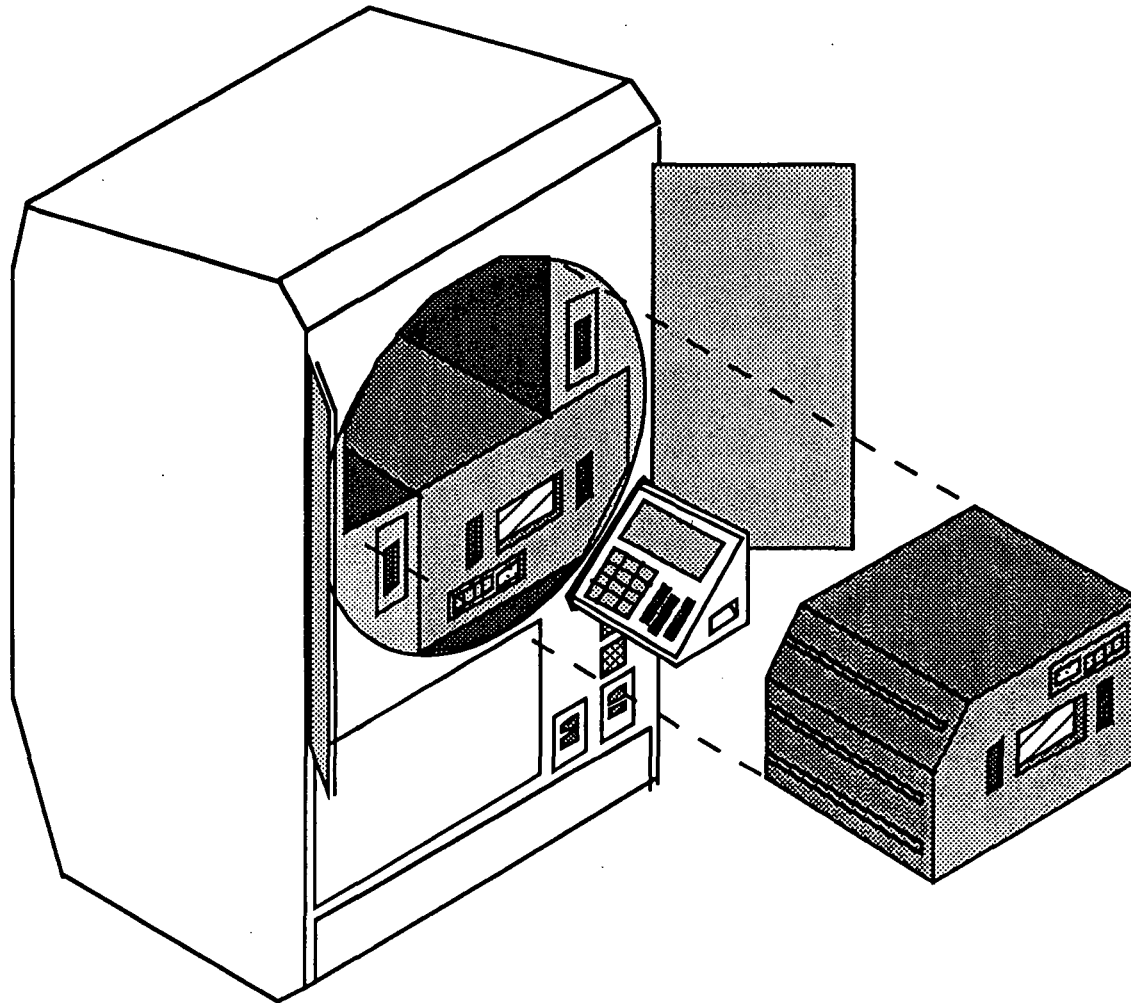
RAT NECROPSY PROCEDURE (CONT'D)

8) Glovebox Shut Down:

- i) Wipe down all surfaces of work volume; recirculate work volume air for 15 minutes; bag all remaining trash;
- ii) Squeeze trash bags to evacuate air; seal trash bags; place all trash bags within gloveport bag;
- iii) Squeeze gloveport bag to evacuate air; use heat sealer to seal bag; cut bag; transport bag to the solid waste disposal system;
- iv) Check contamination sensors; when SMAC levels are met within work volume, turn off blowers; turn off other components; push work volume into stowed position;

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 8 Specimen Chamber Service Unit



INTRODUCTION

The adjacent page presents an outline of the Specimen Chamber Service Unit chapter of this report.

OUTLINE

- PRIMARY REQUIREMENTS
- SYSTEM DESCRIPTION
- SYSTEM CHARACTERISTICS
- EXTERNAL INTERFACES
- TRADEOFFS
- SCHEDULING
- REQUIREMENTS NOT MET
- AREAS REQUIRING FURTHER STUDY
- TECHNOLOGY DEVELOPMENT
- SUMMARY
- APPENDIX

PRIMARY REQUIREMENTS

The role of the Specimen Chamber Service Unit is to provide clean specimen chambers to house the plants and animals used in life science experiments. The method by which the Service Unit does so is left open to the designers. Regardless of the method selected, the Service Unit must provide specimen chambers free of particulate and nonparticulate contamination. The surfaces of clean specimen chambers must also contain less than 50 Colony Forming Units (CFU) of microorganisms per 100 cm². If a cleaning method is used to supply clean chambers, the procedures, materials and residues associated with such a method must not be deleterious to the specimens.

PRIMARY REQUIREMENTS

Science requirements that affect the design:

- Provide clean specimen chambers free of particulate and nonparticulate contamination
- Provide clean specimen chambers with less than 50 Colony Forming Units of microorganisms per 100 cm²
- Avoid exposing specimens to harmful cleaning procedures, materials, and residues

PRIMARY REQUIREMENTS (CONT'D)

The Service Unit must provide specimen chambers that have been cleaned, sanitized, and disinfected. Sterilization of the specimen chambers is not required. The Service Unit must be capable of supplying enough chambers to support a variety of science scenarios. Regardless of the way the Service Unit provides clean chambers, the method must meet the strict Facility bioisolation requirements. This includes the prevention of cross contamination between the crew and the specimens.

The Service Unit should need only one person to operate it. It should be designed to accommodate all possible users, ranging from the 5th percentile Japanese female to the 95th percentile American male. The Unit shall be fully functional under both zero-g and one-g conditions. The overall design should provide features that assist in maintaining the system, including routine cleaning and decontamination.

Wastes produced from chamber servicing must be handled by the Service Unit. This includes the short term storage of all solid and liquid wastes that may be generated. The baseline PMMS should be able to provide long term storage and/or processing of wastes. Lastly, the Service Unit must limit its dependency on other Space Station Freedom resources, such as water and electrical power.

PRIMARY REQUIREMENTS (CONT'D)

Functional requirements that drive the design:

- Clean, sanitize, or replace specimen chambers on orbit
- Provide sufficient number of clean specimen chambers to support non-human life science experiments
- Provide clean specimen chambers while maintaining bioisolation
- Require not more than one operator
- Satisfy the anthropometric requirements of all users
- Operate at micro-g levels and on Earth
- Facilitate maintenance, cleaning, and decontamination
- Provide capability for waste management
- Limit dependence on Space Station Freedom resources and resupply

CLEANLINESS DEFINITIONS

Although sterile chambers may be preferred by some experiments, the overall impact of providing a method of sterilization and the attendant verification process was judged to be excessive. Therefore the requirement is for the Specimen Chamber Service Unit to provide chambers that have been cleaned, sanitized, and disinfected. This means that dirt and most microorganisms must be removed.

Specifically, the Service Unit is required to sanitize and disinfect specimen chambers to a level of 50 Colony Forming Units/100 cm². To do so, the Service Unit uses the guidelines followed by the restaurant industry for sanitizing equipment. The guidelines established by the National Sanitation Foundation call for using water heated to 143°F for 60 minutes, or hotter water for shorter durations of time.

CLEANLINESS DEFINITIONS

Cleaning: The process of removing dirt or impurities.

Sanitization: The process of reducing the number of microbial contaminants on an inanimate surface.

Disinfection: The process of destroying most or all disease causing microorganisms, not including spores or viruses.

Sterilization: The process of destroying all forms of microbial life on inanimate surfaces. The absolute means of total decontamination.

The baseline design of the Service Unit will clean, sanitize, and disinfect the specimen chambers.

SYSTEM DESCRIPTION

The baseline design of the Specimen Chamber Service Unit from this study provides clean specimen chambers by washing soiled specimen chambers with hot water and detergent. During servicing, the specimen chambers are housed inside enclosed units called wash modules. The wash modules contain the sprayers and drains to circulate water and air around the chambers. While in the Service Unit, the wash modules are mounted onto a rotor which spins and provides the centrifugal force to force water off of the chambers. The wash modules can be removed from the rotor and transported to the Life Sciences Glovebox where equipment can be transferred into or out of the modules. The modules slide in and attach to the Glovebox in the same manner as Habitats.

The crew can control the Service Unit via a control panel that slides in and out of the front of the rack. This panel contains the necessary buttons and control switches, as well as displays showing important status information. The front of the rotor is covered by protective panels that serve as a safety shield. These panels are hinged and can be opened to access the wash modules and filter modules. The filter modules are fully enclosed units that remove particulates from the water stream and are designed for rapid replacement.

Water used in the wash and rinse cycles is reclaimed by the Vapor Compression Distillation System (VCDS). The VCDS occupies the bottom front quarter of the rack, and is sufficient to handle the water needs of the Service Unit.

This design of the Service Unit has been oriented towards satisfying the requirements of the Centrifuge Facility. Although other payloads may need to use the Service Unit, their requirements haven't been addressed. However, the baseline Service Unit is a flexible system that should serve most, if not all, possible users.

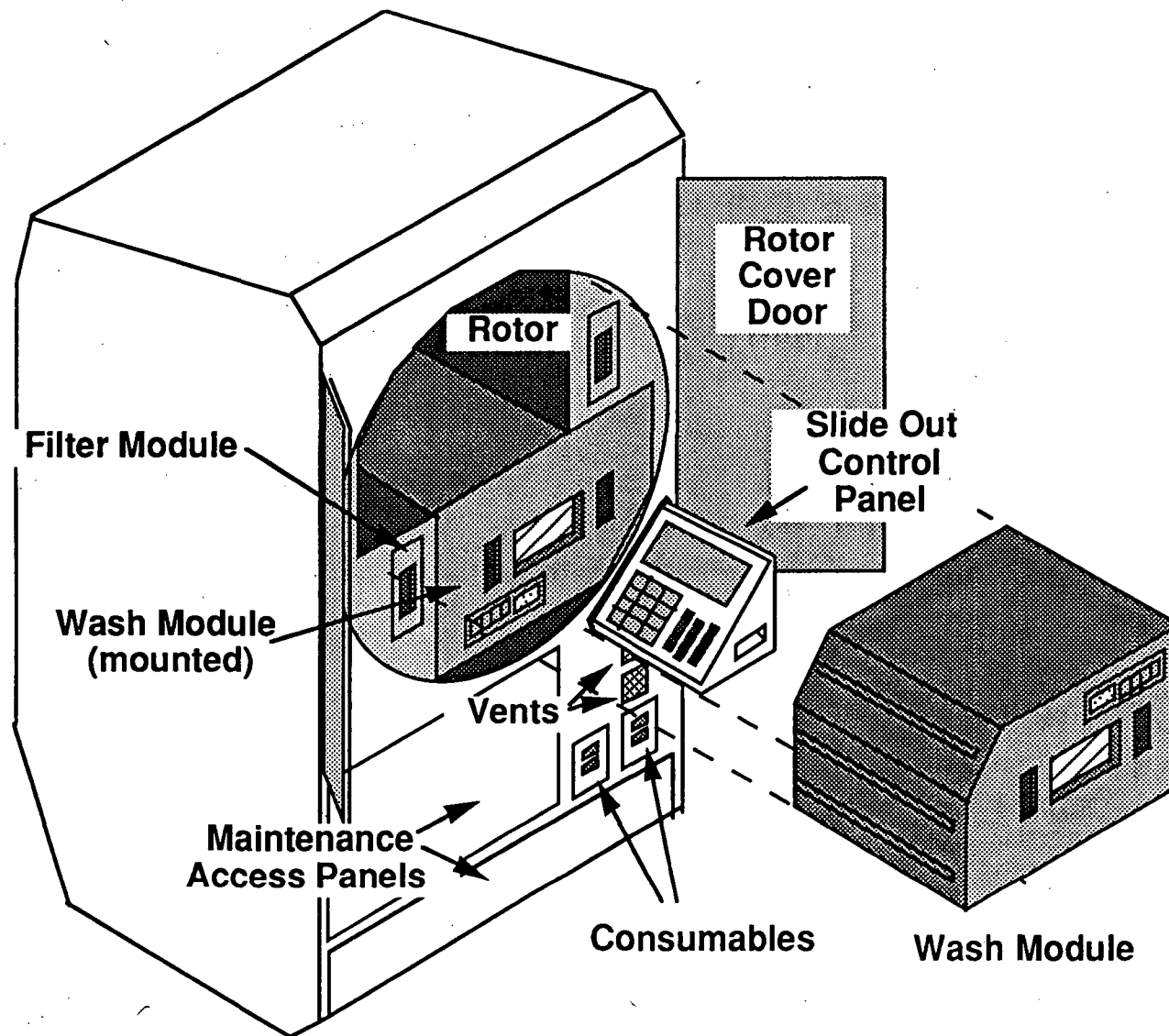
SYSTEM DESCRIPTION

- Hot water and detergent washer
- Specimen chambers and equipment are washed inside modules
- Wash modules attach to rotor on the Service Unit
- Items transferred to/from wash modules at the Life Sciences Glovebox
- Wash modules interface with the Life Sciences Glovebox in a similar manner as Habitat modules
- Crew interfaces with Service Unit via slide-out control panel
- Vapor Compression Distillation Subsystem (VCDS) used to recycle water
- Design optimized for the Centrifuge Facility but may accommodate other users

SYSTEM DESCRIPTION (CONT'D)

The figure on the facing page illustrates the main features of the Specimen Chamber Service Unit as described in the previous pages.

ISOMETRIC VIEW



SYSTEM DESCRIPTION (CONT'D)

In some respects, the wash modules are similar to Modular Habitats. They are designed both to contain specimen chambers, and to be opened only at the Life Sciences Glovebox. However, the wash modules are designed to contain the specimen chambers for washing purposes only. They are not meant to serve as Habitats for specimens.

The wash modules have quick disconnects on the back side for water and air exchange. Fluid entering the wash module would pass through a network of sprayers, flow through and around the equipment that is being washed, and collect at the drainage end of the module. At the drain, there is a coarse filter that prevents large particulates from clogging the fluid lines. The fluid would then exit the wash module and pass through the Service Unit fluid processing equipment. The Service Unit air and water flow systems will be discussed in greater detail later on.

The wash modules contain a basket to which items are attached. At the Glovebox, the cover to the wash module and Life Sciences Glovebox door seal together and lift off as one piece. Once the cover is removed, the basket can be lifted out to remove or attach equipment. Each wash module also contains a transparent window which allows visual inspection of the specimen chambers without opening the module.

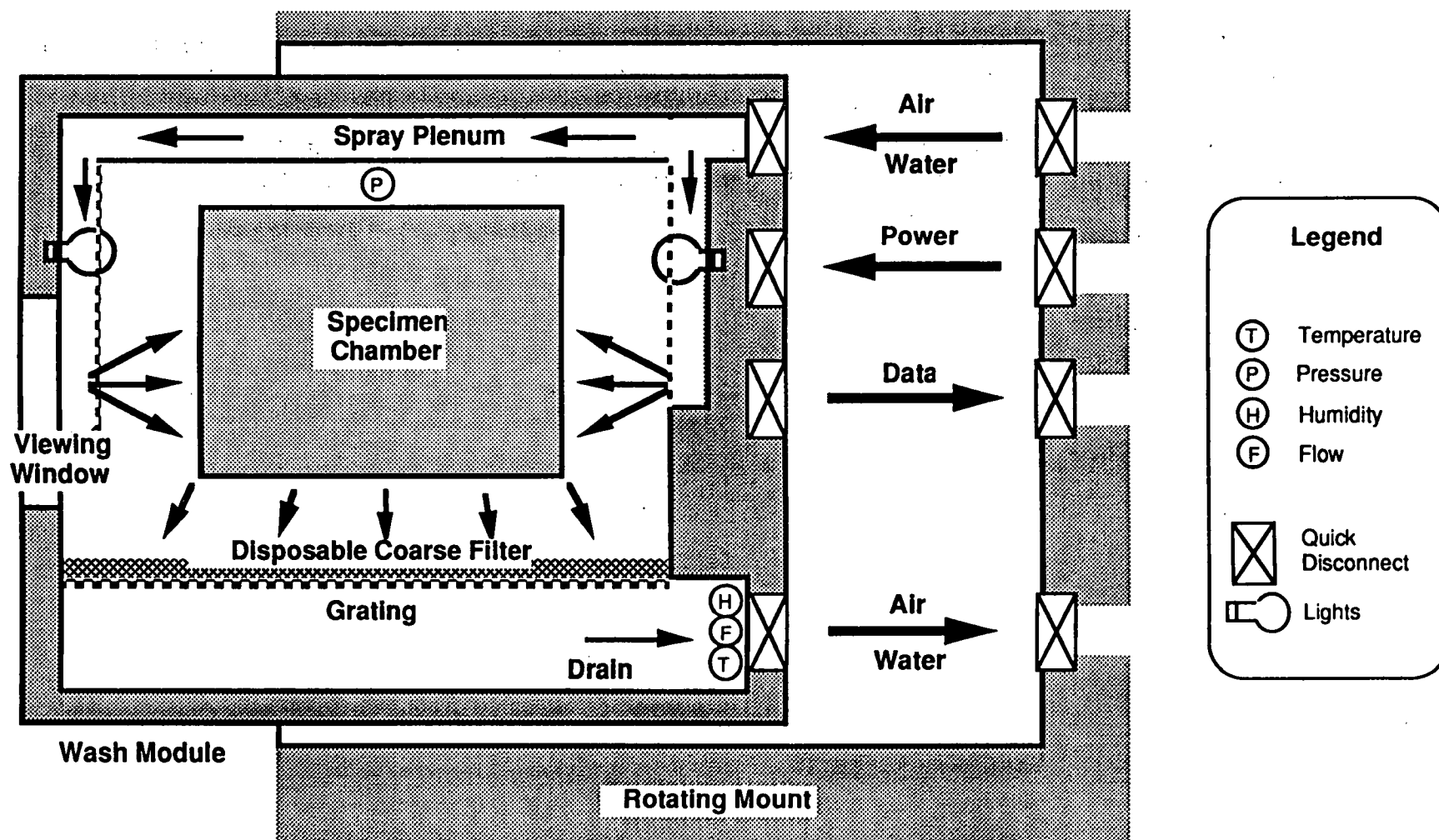
WASH MODULE

- Specimen chambers and waste trays transferred to/from the wash modules at the Life Sciences Glovebox
- Each wash module will have the same door interface to the Glovebox as the Modular Habitat
- Equipment or chambers attach to a basket that pulls out of the wash module
- Two wash modules slide in/out of rotor
- Each wash module connects to the Service Unit air and water lines and contains the spray nozzles and drainage gutters
- Each wash module can house either
 - 2 rodent specimen chambers with waste trays
 - 1 squirrel monkey specimen chamber with waste tray
 - 1 unpartitioned plant specimen chamber
 - 3 partitioned plant specimen chambers
 - TBD quantity of equipment

SYSTEM DESCRIPTION (CONT'D)

The wash module is designed to house the specimen chambers during servicing and serve as a carrier to the Glovebox. The water and air that enter and exit the wash modules are processed by pumps, fans, filters and other equipment inside the Service Unit. The Service Unit also provides the wash modules with additional utilities. Power is supplied to drive the lights inside the modules. Lights are used to illuminate the interior for viewing inside the modules. An output line for data is also provided to relay information from the temperature, pressure, humidity, and flow sensors inside the wash module.

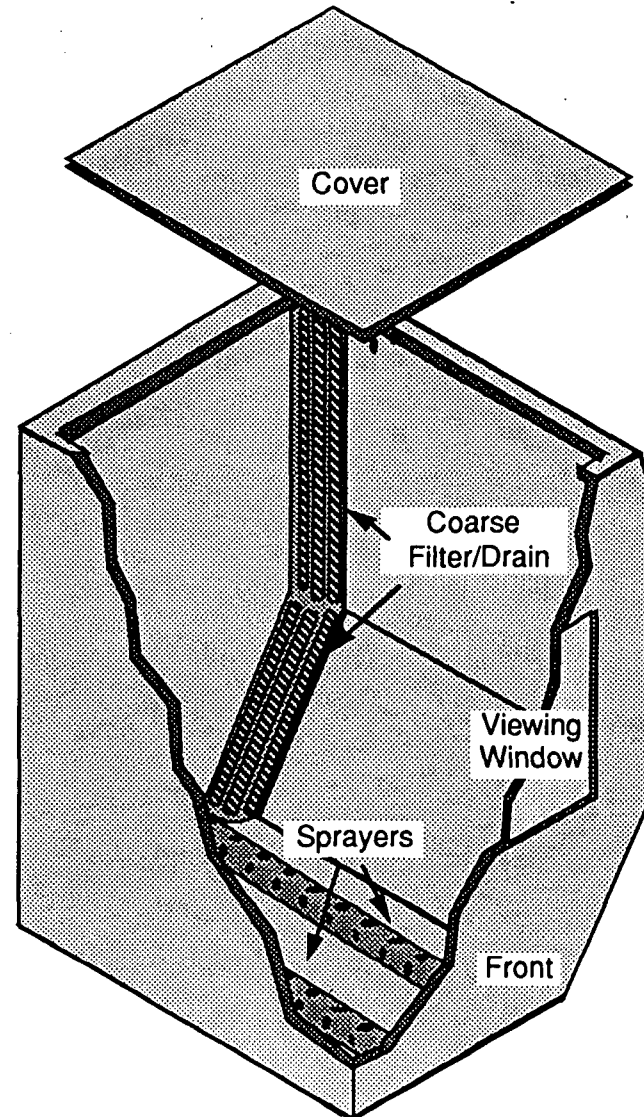
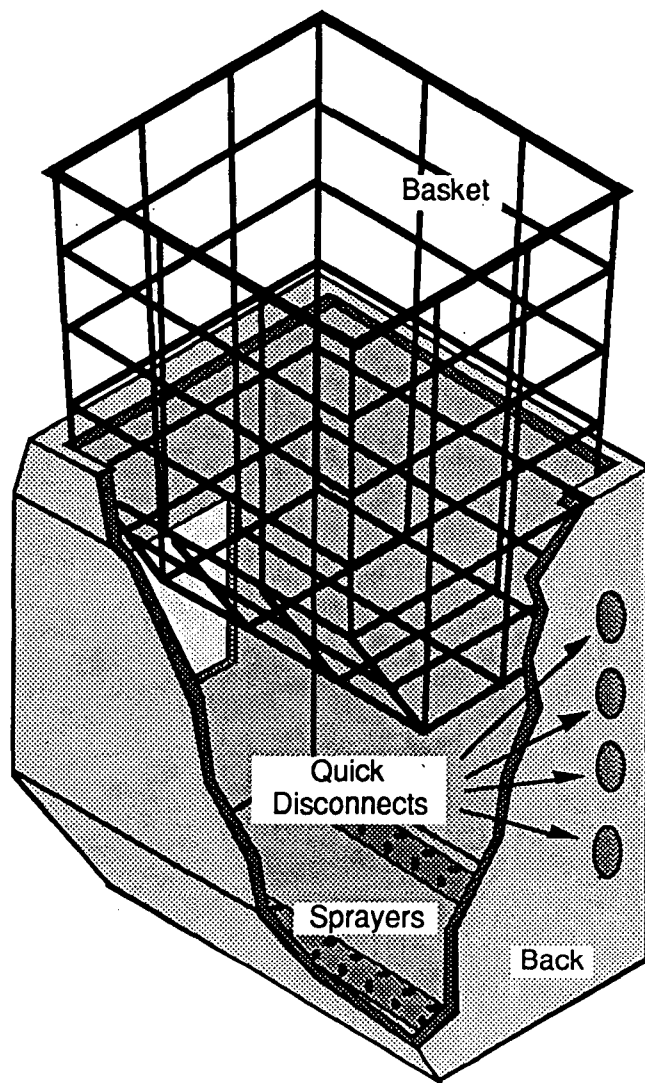
WASH MODULE INTERFACE DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The exploded views of the wash module illustrate its main components. The cover seals to the Glovebox door in the same manner as the Habitat covers. Once the top cover is removed, a basket can be removed from the wash module. The basket would contain the equipment or chambers to be washed. The basket fits inside the wash module shell structure, which also includes the quick disconnects, water sprayers, and drainage gutter. The drain incorporates a filter element to remove coarse particulates.

WASH MODULE

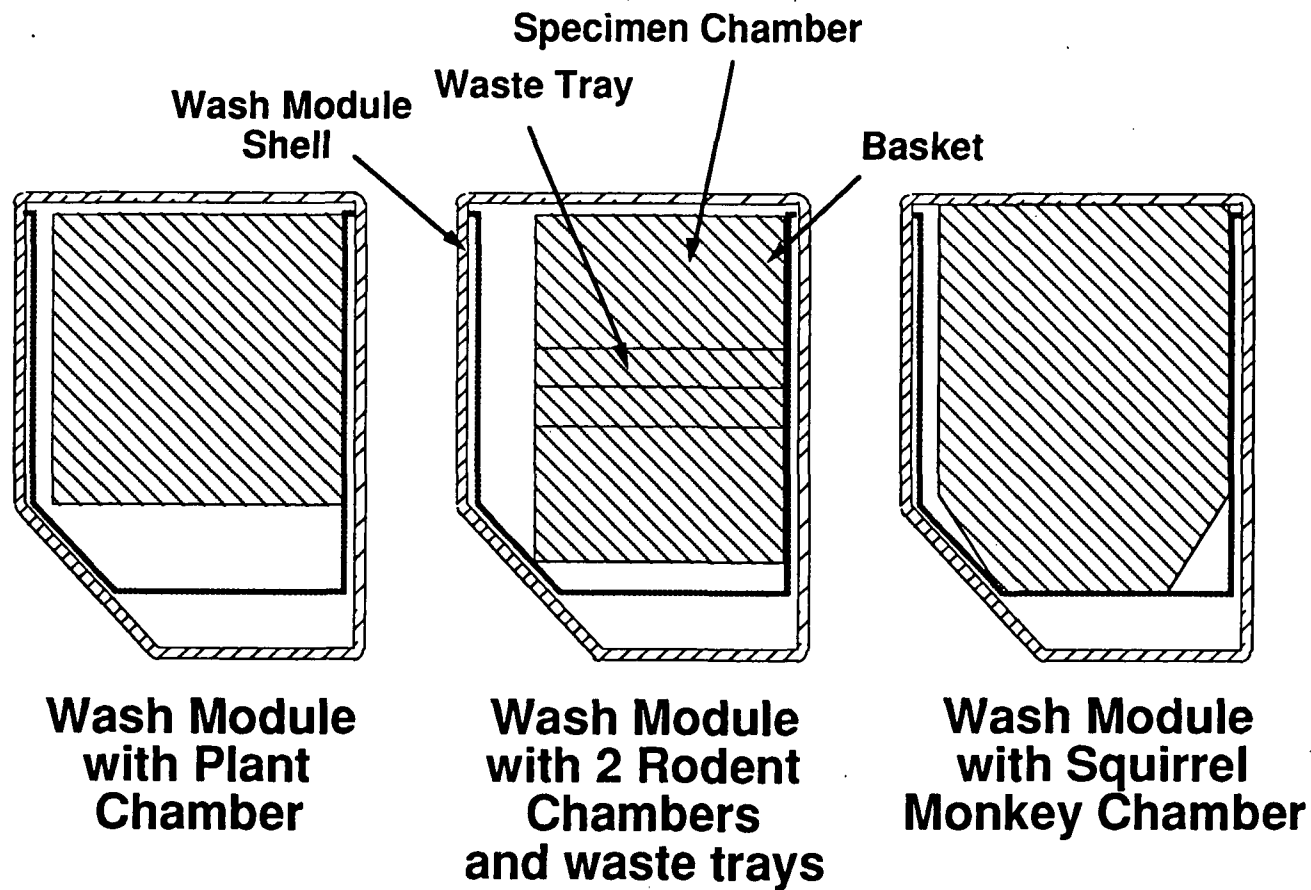


SYSTEM DESCRIPTION (CONT'D)

The wash module has been sized to contain different combinations of specimen chambers. Up to 2 rodent chambers, or 1 restrained or unrestrained squirrel monkey chamber can fit inside a module. The squirrel monkey waste tray can fit within the specimen chamber to be washed, or be thrown away. Alternatively, 1 unpartitioned or 3 partitioned plant chambers can fit inside a module. In another possible configuration, different size and shape laboratory equipment can be placed inside the modules for washing.

The waste trays of the animal chambers will also fit inside the wash module. The waste tray for the squirrel monkey must be placed within the specimen chamber to fit within a wash module. If these waste trays are disposed of rather than cleaned, washing operations would be simpler. Presently, the baseline configuration has washable waste trays with disposables left as an option.

SPECIMEN CHAMBER CONFIGURATIONS



SYSTEM DESCRIPTION (CONT'D)

The Service Unit makes use of multiple wash and rinse phases to clean the specimen chambers. Each phase requires 5.6 liters (1.5 gallons) of water. The first rinse cycle of a wash load uses water from the last rinse phase of the previous wash load. Since this initial rinse is meant to just remove loose particles and presoak the chambers, the cleanliness of this water is not of concern.

All the other wash and rinse phases use clean water. Some of the phases use hot water to assist in killing microorganisms. The water is heated prior to washing by an electric immersion heater inside the water storage tank. Water at a minimum temperature of 145°F circulated for 90 minutes will suffice to reduce the number of microbes to the desired levels. This process exceeds the standards defined by the National Sanitation Foundation. Use of a disinfectant also facilitates in sanitizing equipment.

A similar pattern of wash and rinse phases was used by McDonnell Douglas (contract NAS9-17475) to clean simulated specimen chambers covered with animal waste matter. Tests after washing showed that the majority of the items were cleaned to the desired level. One problem observed involved shadowing effects produced when the water spray was unable to cover all areas. This Service Unit design will operate with the rotor alternating directions during different wash phases to avoid shadowing effects.

The total time to wash a full load of specimen chambers is 2 hours. The time to recover water from that wash requires an additional 12 hours. The next wash cannot be started until the recycling is complete, so chamber servicings must be spaced at least 17 hours apart. This time includes the 3 hours required to preheat the water. If preheating is not required (cold water wash), the minimum spacing between washes is reduced to 14 hours.

WASH PHASES

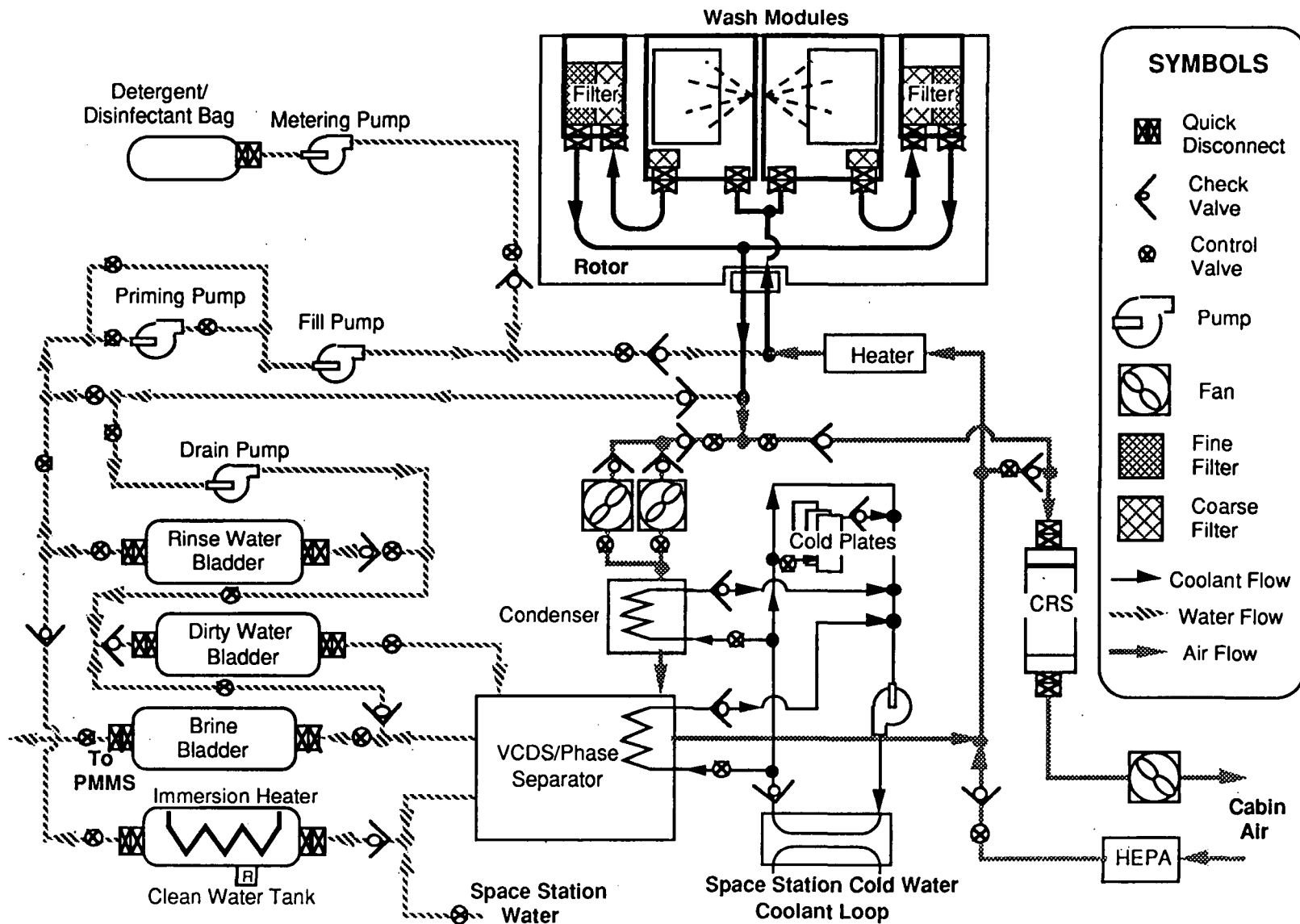
PHASE	FUNCTION	TIME
• Preheat	Heat water past 145°F	3 hours
• 1st Rinse	Wash away loose particles and presoak soil on specimen chambers with old rinse water	10 minutes
• 1st Wash	Wash away soil and kill microorganisms using hot water, detergent, and disinfectant	15 minutes
• 2nd Rinse	Remove residue remaining from 1st wash cycle	10 minutes
• 2nd Wash	Wash away soil and kill microorganisms using hot water, detergent, and disinfectant	30 minutes
• 3rd Rinse	Remove residue remaining from 2nd wash cycle	25 minutes
• 4th Rinse	Remove all remaining residue	10 minutes
• Dry	Remove moisture by blowing hot air	20 minutes
• Recycle	Process dirty water to reuse in subsequent wash	12 hours

TOTAL: 17 hours

SYSTEM DESCRIPTION (CONT'D)

This block diagram shows the fluid system concept for the Service Unit. It illustrates the pathways followed by air, water, and coolant, as well as the primary components of the Service Unit. More importantly, it provides an overview of the Service Unit fluid systems, detailing how the different systems interact. In the following pages, each system is detailed in separate block diagrams for greater clarity.

SYSTEM BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The water flow system is a complex network of pipes, storage bladders, and pumps. The water used in the first rinse cycle comes from the rinse water bladder, and is water that was used in the last rinse cycle of the previous wash load. The system is initially primed with this water by a peristaltic pump. Once the system is primed, the water cycles through the wash modules and filters via the fill pump (the peristaltic pump is bypassed.) At the end of the first rinse phase, water is drawn by the drain pump and discharged into the dirty water storage bladder. The bladder has a capacity of 7.5 gallons.

Water for the subsequent wash and rinse phases comes from the clean water storage tank (capacity = 7.5 gallons). The water inside the tank is heated to above 145°F by an electric immersion heater. Water is drawn and circulated by the fill pump. Once the cycling of water is complete for that phase, the water is syphoned by the drain pumps and directed to the dirty water storage bladder. During the wash phases, the recirculating water is mixed with detergent and disinfectant to facilitate cleaning.

After the final wash phase, water is drained into the rinse water storage bladder rather than the dirty water storage bladder. This water is stored until it is used during the first rinse of the next wash load. The water inside the dirty water storage bladder is processed by the vapor compression distillation system to reclaim the water. Product water is stored inside the clean water storage tank and brine is held inside a separate container.

The water is sprayed over the specimen chambers while they are inside the wash modules. Run-off from the specimen chambers is driven to one end of the module and passes through a coarse filter prior to exiting from the wash module. After leaving the module but while still on the rotor, the water passes through a series of filters graduating from coarse to fine. These filters remove solid particulates, and prevent clogging throughout the system of pipes.

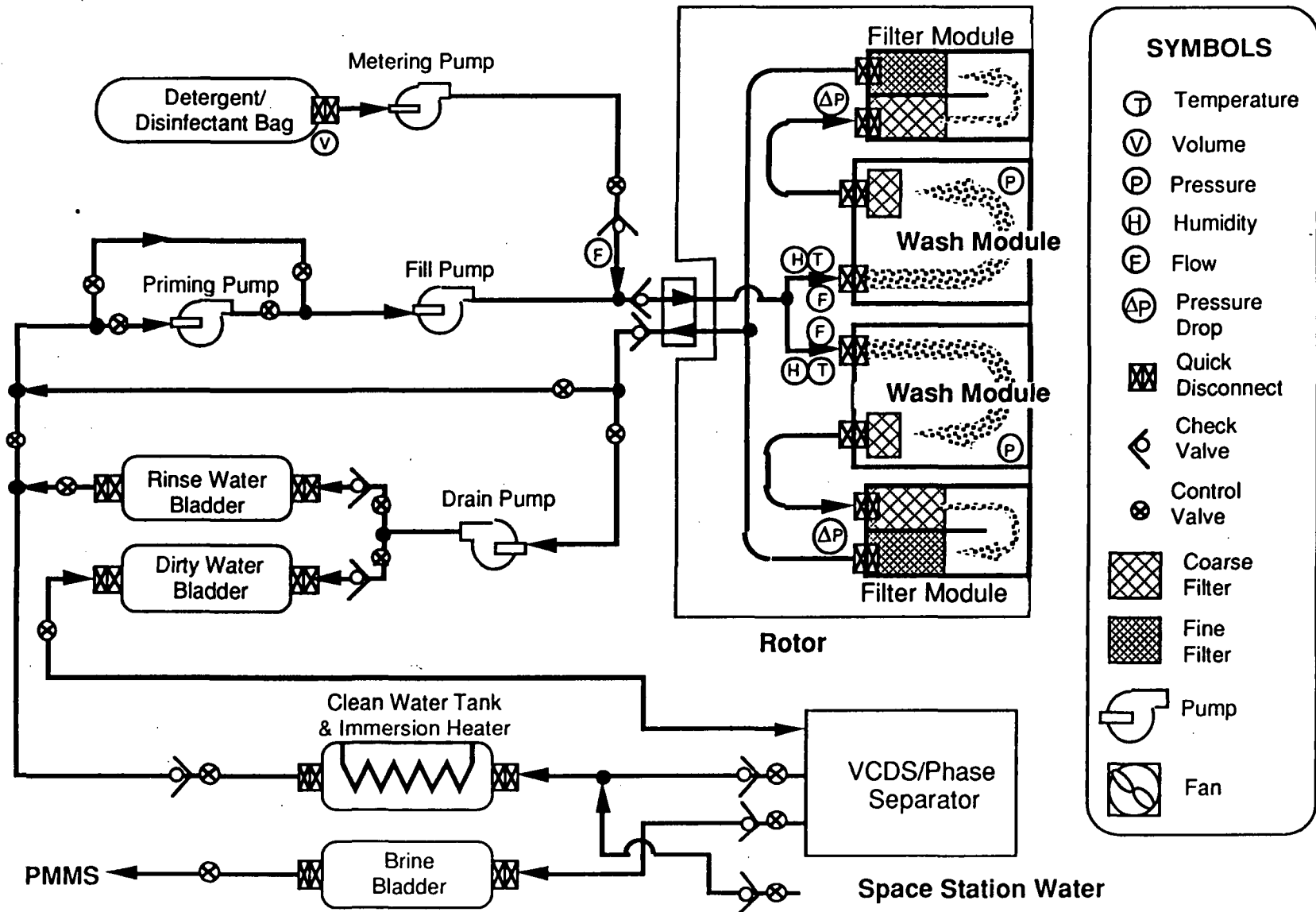
WATER FLOW

- Immersion heater heats water inside clean water storage tank to 145°F
- Priming pump draws water from clean water storage bladder and primes system
- Fill pump circulates wash water at 10 gpm
- Water mixes with a detergent/disinfectant mixture during wash cycles
- Water enters the wash modules and is sprayed onto items to be washed
- Rotary motion forces water across specimen chambers and facilitates collection of water
- Rotation direction switches between clockwise and counterclockwise to avoid shadowing effects
- Water collects in drain of wash modules, and passes through a series of filters
- Drain pump sends water into either the dirty water or rinse water storage bladder

SYSTEM DESCRIPTION (CONT'D)

The following is a diagram of the water flow through the Service Unit. The legend for the diagram is on the right hand side of the chart. The diagram explains the pathway followed by the water stream. Sensor and equipment location is also depicted.

WATER FLOW BLOCK DIAGRAM



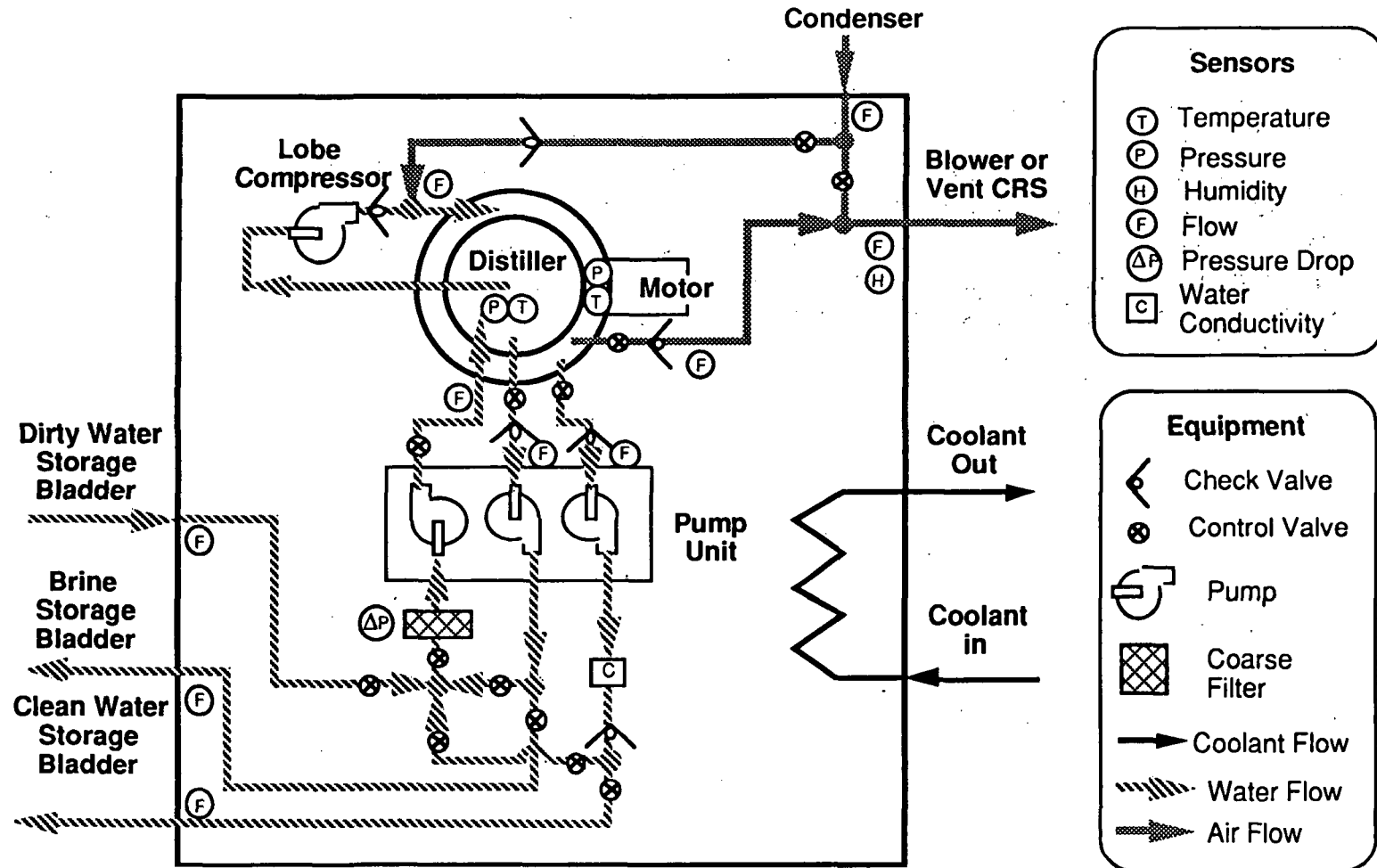
SYSTEM DESCRIPTION (CONT'D)

The chosen method of water reclamation is the Vapor Compression Distillation System (VCDS). The main component of the VCDS is a rotating, double walled distiller. Waste water is pumped into the inner chamber of the distiller, where the centrifugal action of the distiller maintains the air/water separation. Low air pressure is maintained inside the chamber, causing the water to vaporize and separate from its contaminants. The water vapor is drawn by a lobe compressor which increases the pressure of the vapor and raises the saturation temperature. The compressed vapor is passed back into the distiller, entering the gap between the inner and outer wall. As the vapor contacts the inner wall, it condenses and the wall conducts latent energy through the thin metal wall and into the inner chamber. This energy is used to evaporate the waste water on the inside of the inner wall.

The rotating action of the distiller forces liquid to the inner side of the cylindrical walls. This component is similar in function to phase separators that have been used on previous space flight systems. To save space, the baseline Service Unit makes use of the distiller as an air/water phase separator. The phase separator will be used during the air dry phase of the wash cycle. Humid air will be chilled by a condenser to the dew point, and then sent to the distiller to remove the condensate.

Water recycling and air drying occur at different times. There should be no conflict in using one mechanism to serve both functions, although no tests have been undertaken to prove the feasibility of this dual application.

WATER RECLAMATION SUBSYSTEM



The Vapor Compression Distillation Subsystem (VCDS) incorporates a rotating distiller which separates water from impurities. The distiller also doubles as a phase separator to remove condensate from the air exiting the condenser.

SYSTEM DESCRIPTION (CONT'D)

Air is used to dry the specimen chambers. The air is heated by an electric heater to 120°F to increase the water retention capacity of the air. After passing over the specimen chambers, the air is dehumidified by an air-to-water condensing heat exchanger. To separate the air and water in the zero-g environment, the two fluids flow into the rotating chamber of the VCDS. The water that is removed is drained and stored in the dirty water storage bladder. The air is either recirculated, or filtered and passed to the cabin. A total flow of 3 cfm is vented to the cabin, but only after it passes through a small contaminant removal system canister (CRS) similar in size and composition as the vent CRS found in the Life Sciences Glovebox. Three cfm of air is drawn from the cabin to make up for the air that is exhausted.

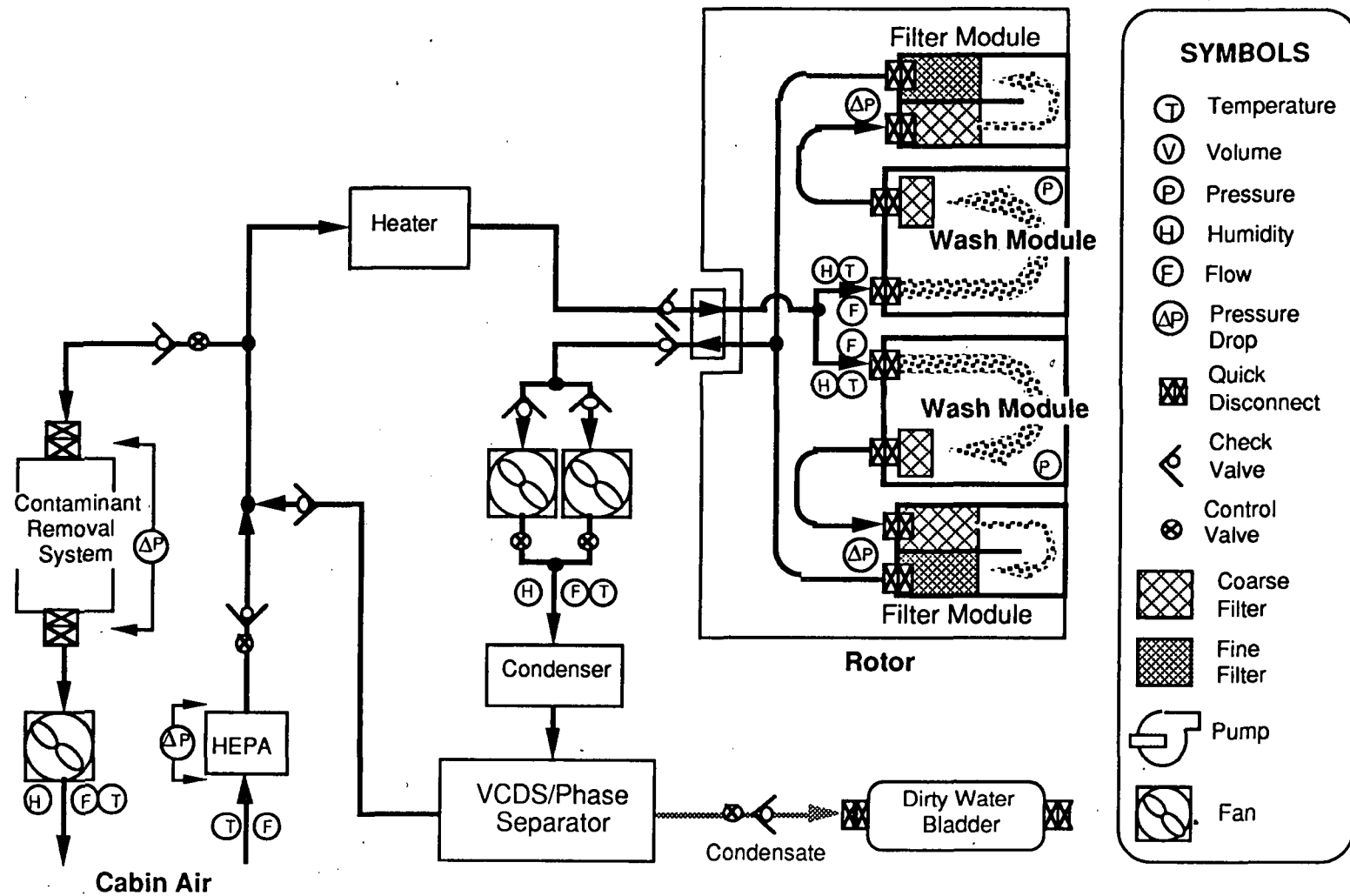
AIR FLOW

- Blowers circulate air at 20 cfm
- Air heater warms air up to 120°F to accelerate specimen chamber drying
- Condenser chills air down to dew point
- Air/water mixture passes through the VCDS distillation unit to separate the 2 phases
- 3 cfm of air vented to cabin after passing through a charcoal and HEPA filter
- 3 cfm of make-up air drawn in from cabin

SYSTEM DESCRIPTION (CONT'D)

The following is a diagram of the air flow through the Service Unit. The legend for the diagram is on the right hand side of the chart. The diagram explains the pathway followed by the air stream. Sensor and equipment location is also depicted.

AIR FLOW BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

Most of the Service Unit thermal dissipation is via the Freedom 4°C coolant loop. The Service Unit interface to the loop is through a water-to-water heat exchanger located at the bottom of the rack. A separate closed loop water line runs within the rack and rejects heat to the Freedom coolant loop via this heat exchanger. The coolant flows through an air-to-water condensing heat exchanger that dehumidifies the air that is used to dry the specimen chambers. The Service Unit coolant loop also runs through cold plates that are attached to components requiring substantial cooling. Control and check valves are located throughout the coolant loop to control the flow and direction of flow of the coolant.

Avionics air will be used to cool areas that are inaccessible by coolant lines or components that have a low thermal rejection load. The avionics air enters the rack through an opening at the top of the rack and exhausts through a connection at the bottom of the rack.

Cabin air will absorb the heat load from exhaust fans and thermal energy that radiates from the wash modules.

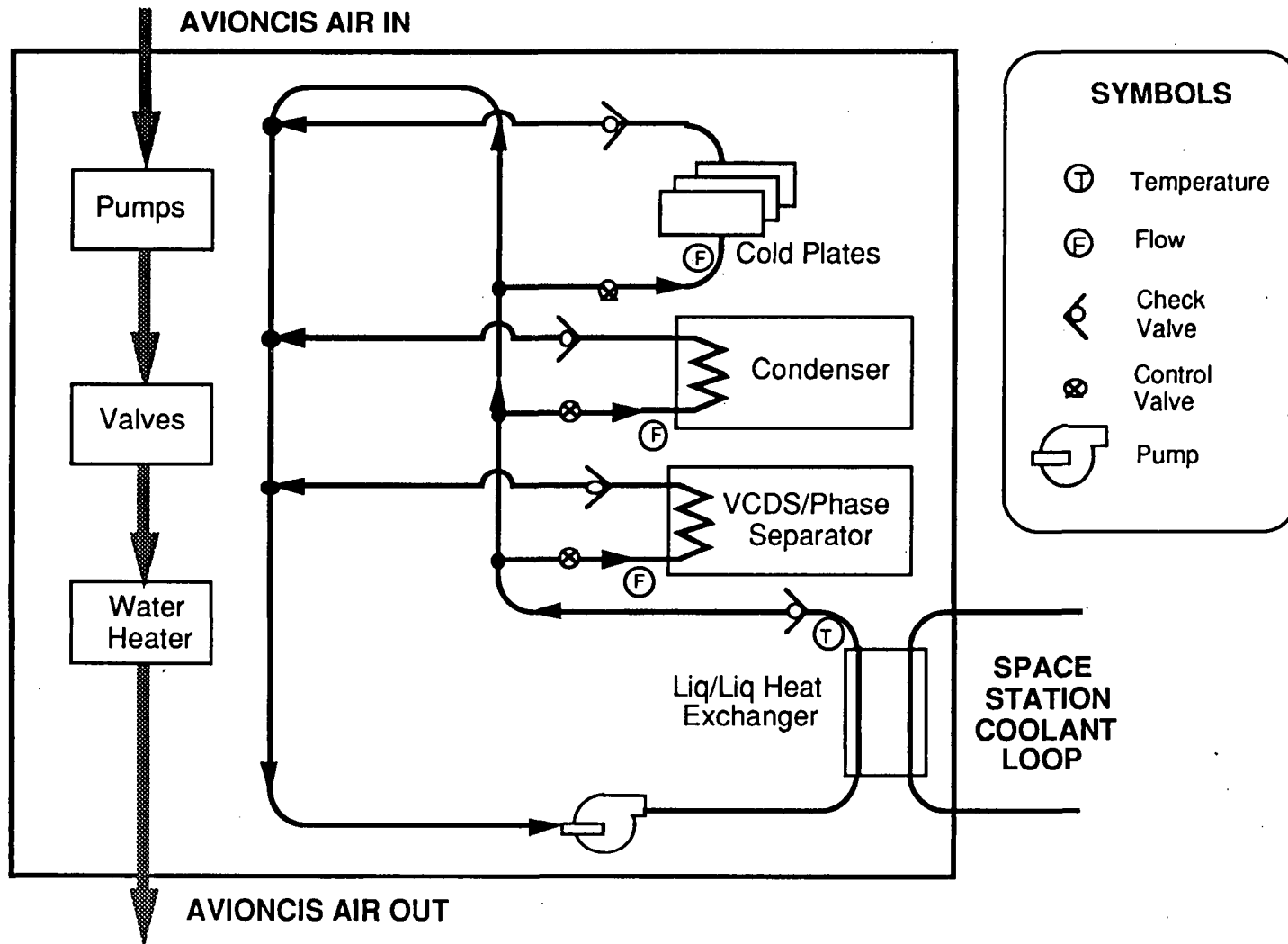
THERMAL CONTROL

- Coolant water cooled within water/water heat exchanger provided by the Space Station
- Water/Water heat exchanger interfaces with the Space Station low temperature water loop
- Coolant circulates through:
 - Air/water heat exchanger condenser
 - Cold plates (which cool MDM/EDP, power electronics, rotating mount motor drive)
- Avionics air circulates within rack and cools the valves, low power electronics, and absorbs some radiant energy from the hot water
- Cabin air serves as a heat sink for exhaust air and some radiant energy from the front of the Service Unit

SYSTEM DESCRIPTION (CONT'D)

The following chart is a block diagram of the Service Unit cooling system. The legend to the diagram is on the upper right hand corner of the page. The diagram illustrates how avionics air and coolant water are used to cool Service Unit components. Avionics air is symbolized on the left hand side with thick dark grey arrows. Coolant water is represented by solid black lines. Coolant water either passes through cold plates bolted to components or through air/water heat exchangers.

THERMAL CONTROL BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

Freedom supplies electrical power to the users at 120 VDC. This power passes through a Power Protection Assembly that controls power input to the rack and acts as a circuit breaker. Power then is transferred to the power electronics, which control the power supplied to each of the components, and convert the raw voltage to different AC and DC voltages. The power electronics are assumed to have an efficiency of 90%.

Power is transmitted across contacting roll rings similar to those cited in the Centrifuge electrical section discussion. Power is required on the rotor and to drive sensors and lights within the wash modules.

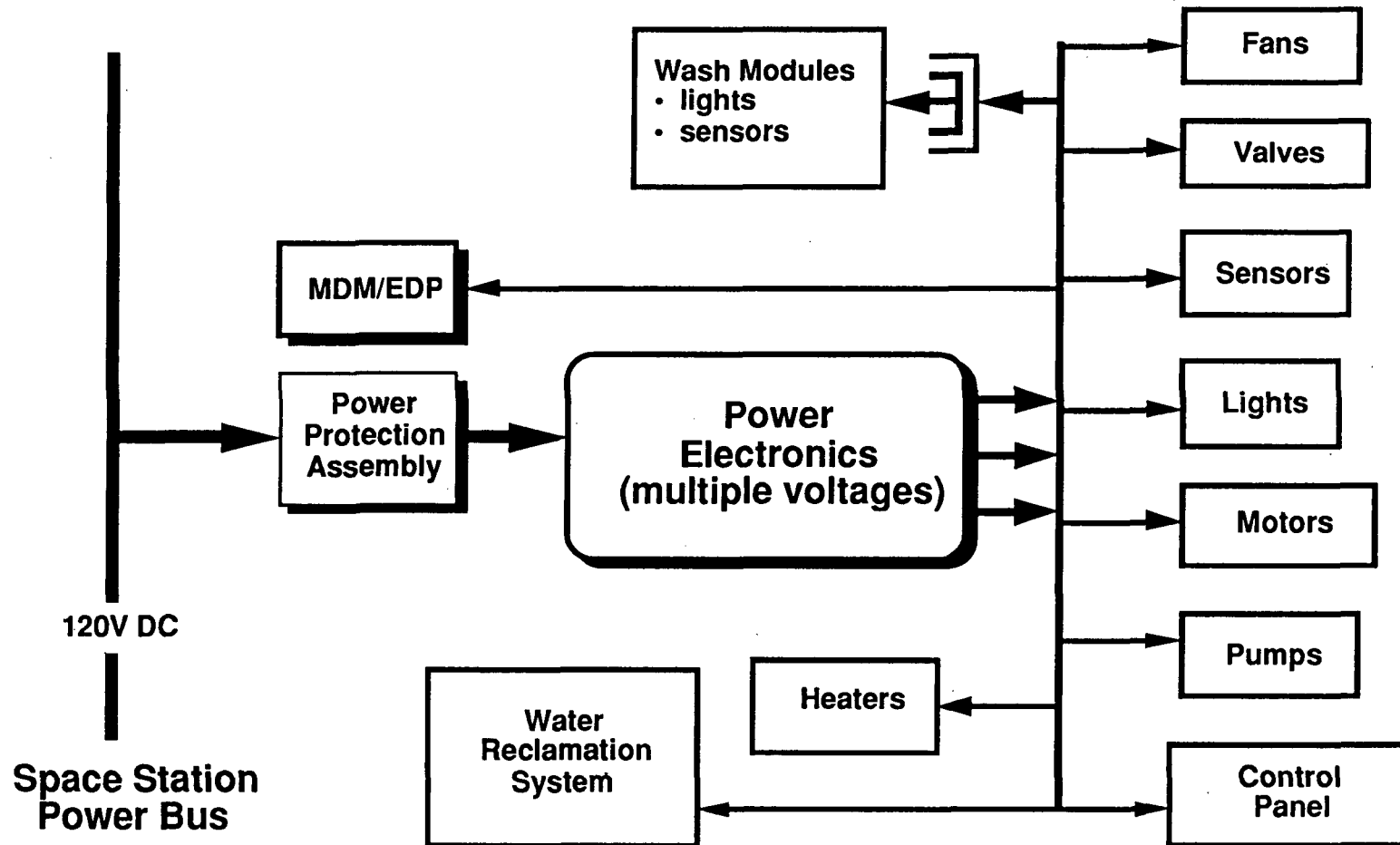
ELECTRICAL SYSTEM

- Power Protection Assembly (PPA) controls power entering the power electronics
- PPA is controlled by the MDM/EDP
- Power electronics convert the 120V DC supply voltage to the desired AC and DC voltages
- Power to rotor and wash modules must be transmitted across a slip ring
- Power electronics are assumed to be 90% efficient

SYSTEM DESCRIPTION (CONT'D)

The following chart illustrates the electrical connections within the Service Unit. The power electronics converts the Freedom supplied power into the voltage levels suitable for driving the different Service Unit components.

ELECTRICAL BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The central controller for data collection and transmission to Freedom is the Freedom supplied Multiplexer/Demultiplexer (MDM). Data is transmitted to and from the Freedom data network via the Network Interface Unit (NIU). The data transferred to Freedom consist of engineering data from the Service Unit subsystems. Signals from the wash modules and rotor must be transmitted across a contacting slip ring within the Service Unit.

The MDM incorporates the Embedded Data Processor (EDP) which provides control for the Service Unit. Commands and control settings are input by crew members via a pull out control panel on the front of the Service Unit. These commands are synthesized by the EDP, which sends signals to the appropriate actuators (valves, fans, pumps, etc.)

It should be noted that the EDP was deleted from the Freedom Program subsequent to the completion of this study. This feature of the design will have to be modified in future studies.

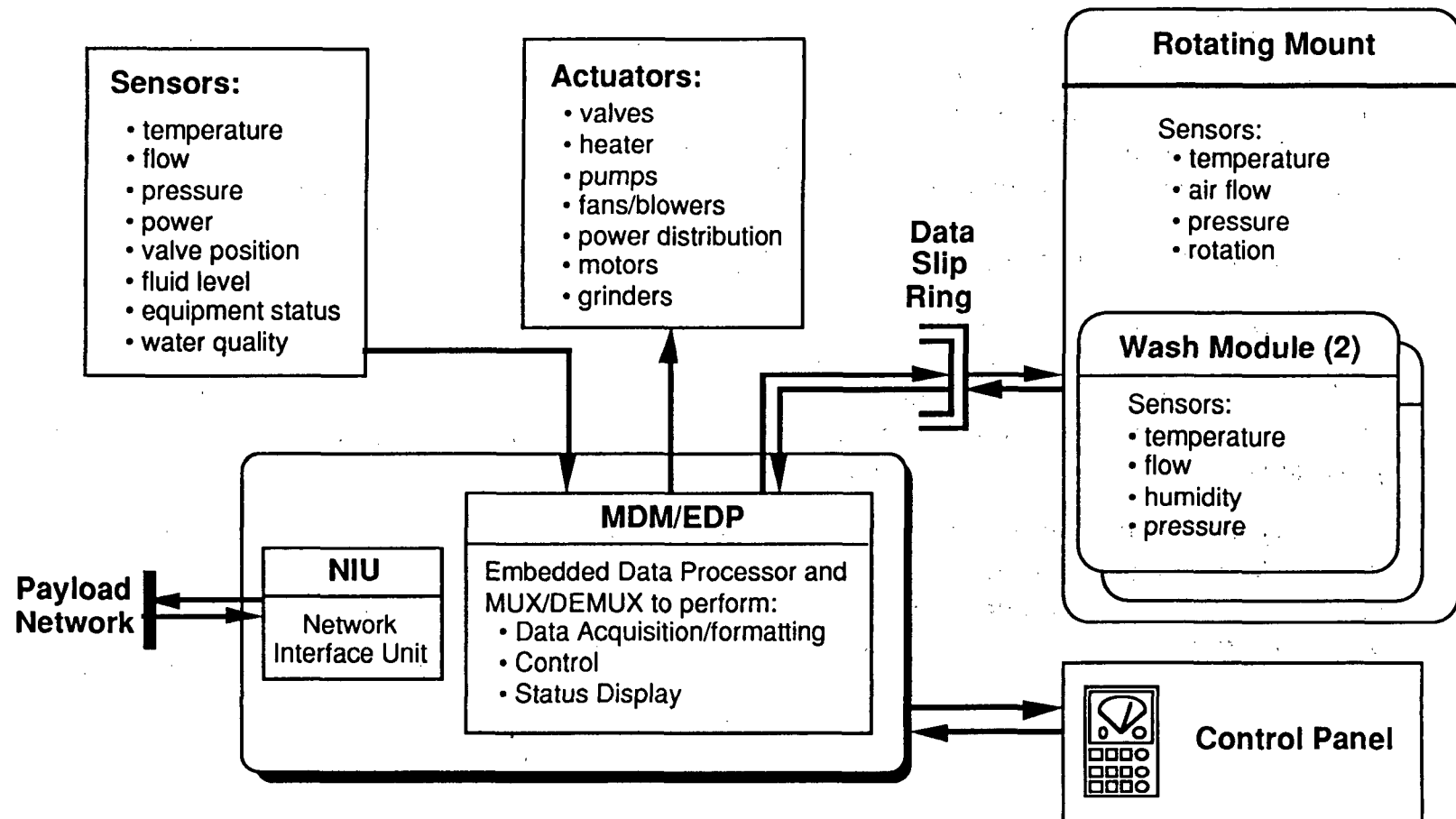
DATA

- MDM/EDP functions:
 - Controller
 - Multiplex/demultiplex data
 - Interface with DMS
- Engineering data generated by temperature, flow, pressure, humidity, rotation speed, and status sensors
- Engineering data from the wash modules and rotor must be transmitted across a slip ring
- Science data - none
- Data can be displayed at the Service Unit control panel

SYSTEM DESCRIPTION (CONT'D)

The following diagram illustrates data flow within the Service Unit . Arrows indicate the direction flow of data and commands. Blocks represent the receivers and transmitters of the information.

DATA BLOCK DIAGRAM



SYSTEM DESCRIPTION (CONT'D)

The wash modules provide a physical barrier separating the soiled equipment from the cabin environment. The wash modules are opened only while they are mounted to the Life Sciences Glovebox. At the Glovebox, the work volume is completely enclosed and sealed to the wash modules. At the Service Unit, the specimen chambers are kept inside the wash modules during washing, rinsing, and drying. Hence, bioisolation is maintained during all specimen chamber handling and servicing operations. To provide an additional level of safety, the wash module incorporates a double wall structure and redundant seals.

During the air dry phase, a negative pressure relative to the cabin is maintained by fans located downstream of the wash modules. This ensures that any leaks would be into rather than out of the Service Unit. If the Service Unit is not washing specimen chambers, it can be used to temporarily house specimen chambers within the wash modules. In such instances, the fans would be operational to provide an additional layer of biocontainment.

Air exhausted to the cabin is scrubbed by multiple HEPA quality filters, activated charcoal, lithium hydroxide, and Purafil to remove airborne contaminants. Condensate and waste water are recycled by the VCDS. Brine from water reclamation is stored inside a multiple walled container which can be disconnected and manually transported to the PMMS.

BIOISOLATION

- Specimen chambers or equipment to be washed are handled in the bioisolated environment of the Life Sciences Glovebox
- All items to be washed are contained within the sealed, double walled wash modules
- Seals within the wash module are redundant
- Fans are located to create a negative pressure within the wash modules during drying
- Fans can be active during times when dirty specimen chambers are stored within the wash modules to create an additional level of biocontainment
- Air vented from the Service Unit passes through a condenser, phase separator (VCDS), HEPA and charcoal filtering before entering the cabin
- Contaminated water and brine are stored in triple wall bladders

SYSTEM DESCRIPTION (CONT'D)

The Service Unit relies on a series of filters to remove particulates that may foul water lines and quick disconnects. Water runoff from the specimen chambers passes through a coarse grade filter at the mouth of the wash module drain. This filter captures large particulates such as hair, fecal pellets, and leaves and needs to be serviced after each wash load. Servicing requires manually removing the matter entrapped by the filter, or disposing of the filter completely. This filter servicing occurs at the Life Sciences Glovebox when the specimen chambers are transferred.

The water that passes through the wash module enters the rotor, where it passes through a series of increasingly finer filters contained inside one removable cartridge. These filters are designed to remove the remaining particulates within the water. The removable cartridge is fully self-contained. Water enters and exits via quick disconnects similar to those found on the wash modules and Modular Habitats. Once the filters inside the cartridge become clogged, the cartridge is disconnected and discarded and a fresh replacement is inserted.

WASTE MANAGEMENT

- Disposable coarse filters inside the wash module drain remove large particulates to prevent clogging through water pipes and quick disconnects
- Coarse filters inside wash modules are removed and disposed of at the Life Sciences Glovebox
- Additional coarse and fine particulate filters downstream of the wash modules remove remaining waste matter from the water
- Filters on the rotor are housed in plug-in cartridges and can be easily connected and disconnected from the front of the rack
- Full brine storage bladders are disconnected from the Service Unit and transported to an appropriate storage area

SYSTEM DESCRIPTION (CONT'D)

The Service Unit makes use of numerous expendables that must be replaced frequently. These items, which include the brine storage bladder, water filter cartridges, detergent, HEPA filter, CRS canister, and waste water pretreatment additives, are located at the front of the rack. The water filter cartridges, detergent, brine bladder, and waste water additives can be accessed directly from the exterior of the rack front. The other items are accessed by opening up the front of the rack. The VCDS is also accessed from the front of the rack.

At the rear of the rack, removable rear panels are provided to get at other components. These components include ducting, water storage tanks, pumps, and the equipment located at the bottom of the rack. To reduce the probability of leaks, the water tanks are triple walled.

Unlike the Glovebox, Holding System, and Centrifuge, the Service Unit does not have a large number of redundant components. Packing limitations inside the rack precluded this. However, the Service Unit will not be operating continuously and will be available for regular maintenance checks to determine the integrity of critical systems. These periodic checks should offset the disadvantage of not having built-in redundant systems.

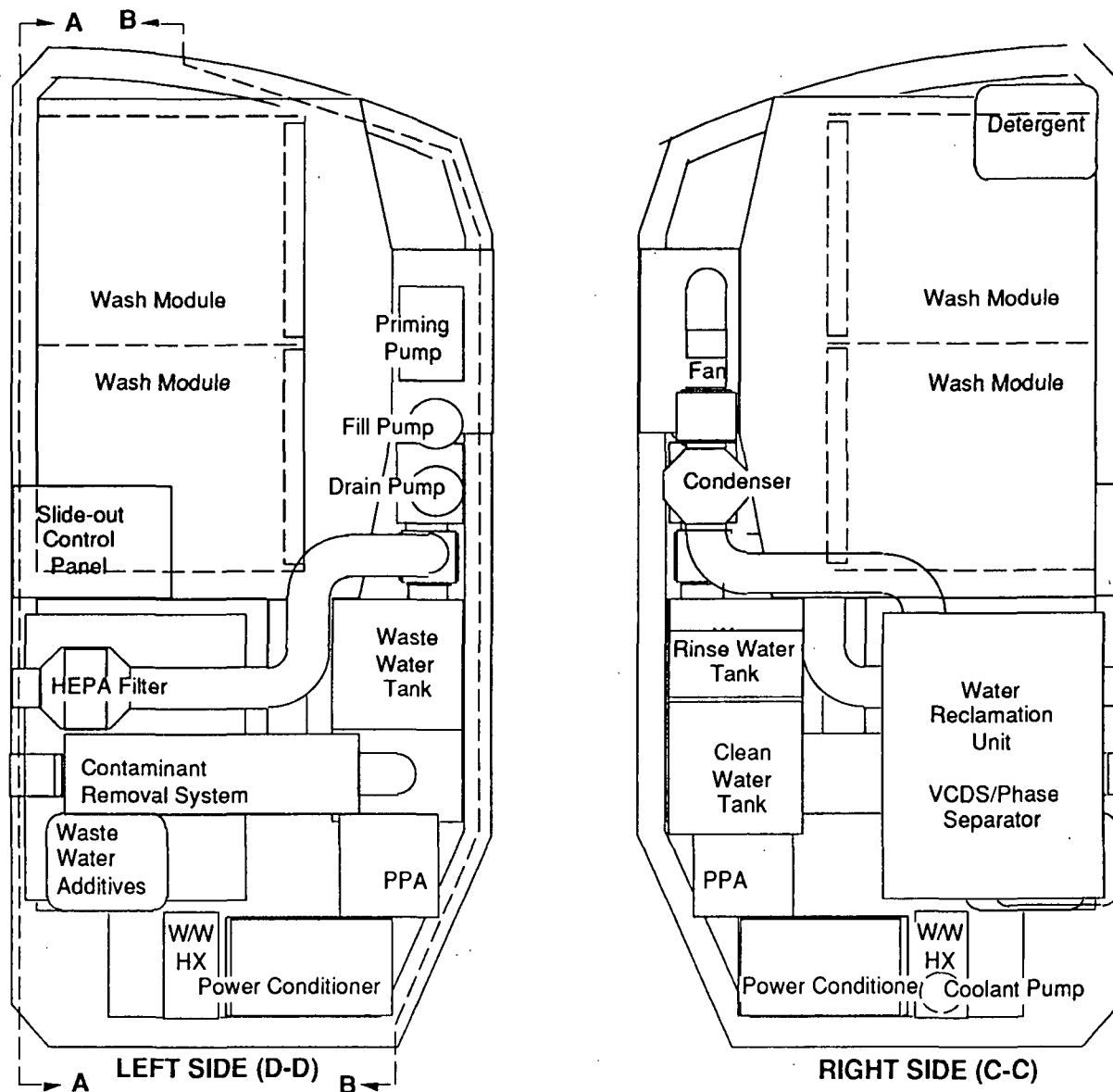
MAINTENANCE

- Expendables accessible from the front of the rack:
 - Brine storage bladder
 - Water filter modules
 - HEPA Filter
 - CRS canister
 - Detergent
 - Waste water pretreatment additives
- Rack front and rear have removable doors to access:
 - Fluid lines and air ducts
 - VCDS
 - Electronic components
 - Pumps
 - Water storage tanks
- Water stored in triple-walled containers
- Intermittent Service Unit use allows for periodic maintenance and repairs

SYSTEM CHARACTERISTICS

The 4 different sectioned views of the Service Unit illustrate the layout of the major components. The top half of the rack is occupied primarily by the rotor, rotary transfer joint, and pumps. The wash modules and filter cartridges are mounted on the rotor. The bottom half of the rack is occupied primarily by the VCDS and water storage tanks. The very bottom of the rack is filled with Freedom supplied components such as the MDM/EDP and water-to-water heat exchanger.

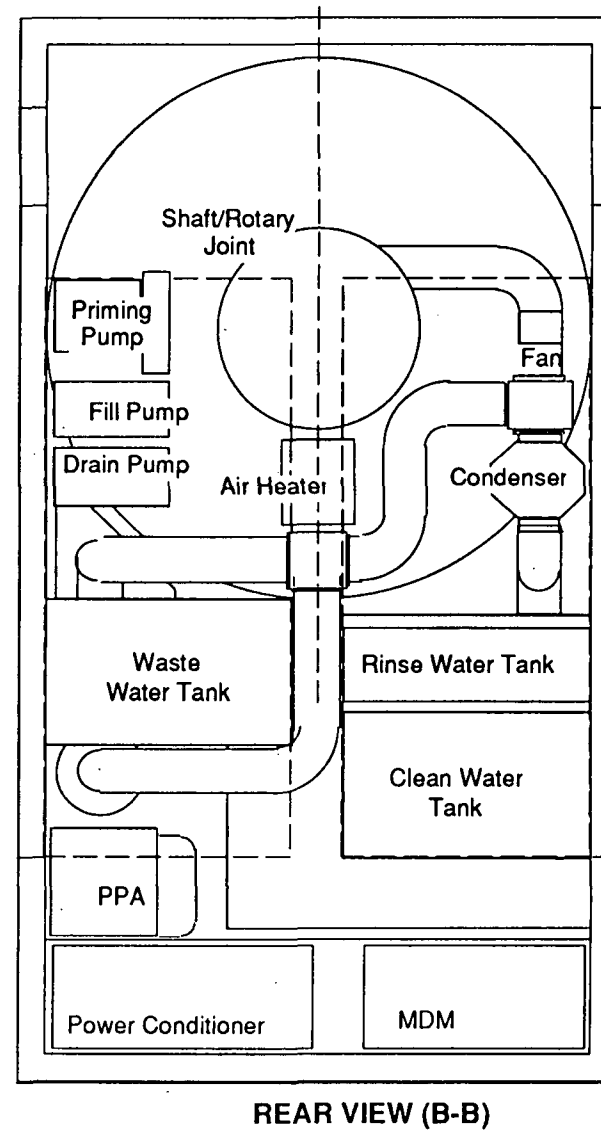
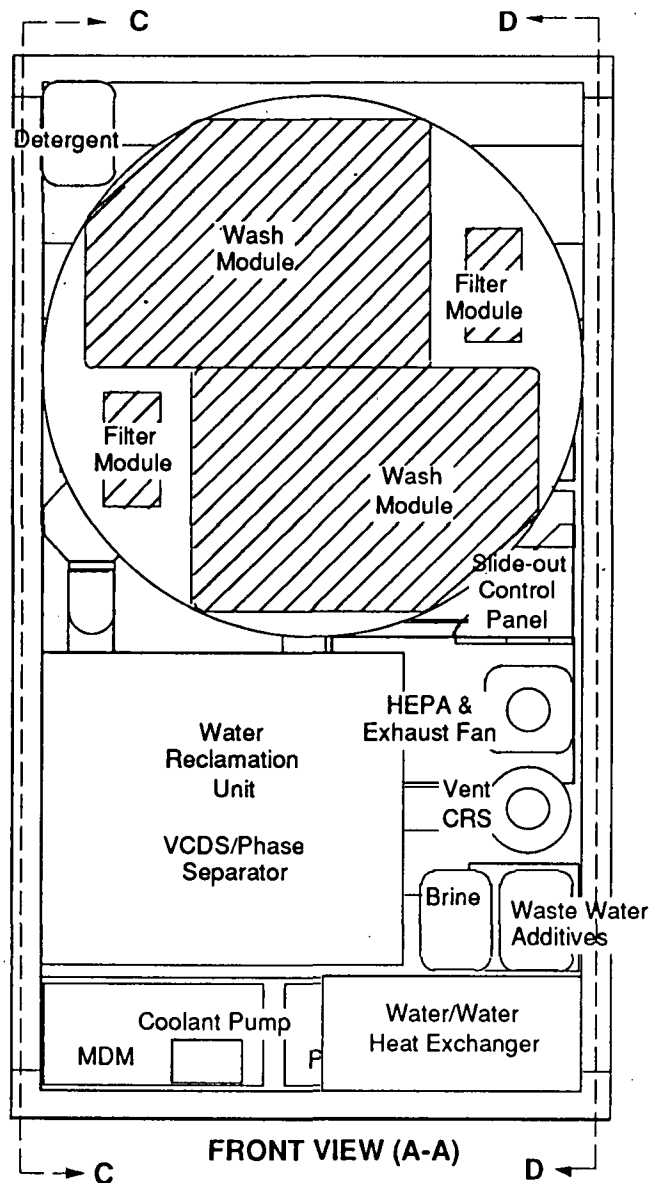
SYSTEM CHARACTERISTICS



SYSTEM CHARACTERISTICS (CONT'D)

All the systems that need to be accessed frequently by the crew are located at the front of the rack. These include the detergent/disinfectant containers, wash modules, filter modules, and slide-out control panel. The VCDS is also located at the front of the rack to facilitate maintenance. Other wet systems that may require periodic checking or repairs are located at the rear of the rack. The rack can be tilted down and rear panels removed to access the pumps, piping, and water storage tanks.

SYSTEM CHARACTERISTICS (CONT'D)



SYSTEM CHARACTERISTICS (CONT'D)

Estimates of the mass and volume of the major Service Unit components were made. These estimates are based on information from various sources. Items like the MDM are being built under contract for Freedom, and the numbers in the following table reflect the latest information we have in describing them. Other equipment estimates are based on modifications of previously flown space flight hardware. For example, the sizing of the CRS canister is based on the Trace Contaminant Control System of the General Purpose Work Station. Other equipment estimates were also based on catalogues of non-space flight hardware. The size and mass estimates of the remaining items were based on engineering judgement and experience.

MASS/VOLUME CHARACTERISTICS

SUBSYSTEM & COMPONENTS	DRY MASS	VOL	BASIS
	kg (lbm)	liters (in ³)	
Consumables:			
- detergent/disinfectant	2.3 (5)	4.1 (250)	calculated
- waste water additives	2.3 (5)	4.1 (250)	calculated
- brine storage bladder	2.3 (5)	4.1 (250)	calculated
- water filter modules	4.6 (10)	8.3 (510)	rough estimate
- HEPA filter	2.3 (5)	0.4 (30)	catalogue
- CRS canister	6.8 (15)	25.9 (1580)	mod. exist. hrdwr.
Electronics:			
- Power Protection Assemblies(PPA)	6.8 (15)	17 (1040)	Freedom supplied
- power electronics	6.8 (15)	6.7 (410)	Freedom supplied
- MDM/EDP	18 (40)	17 (1400)	Freedom supplied
- touch screen	2.3 (5)	3.4 (210)	catalogue
Thermal Control:			
- water/water heat exchanger	11.4 (25)	9.5 (580)	Freedom supplied
- water/air heat exchangers	2.3 (5)	3.8 (230)	catalogue
- cold plates	7.3 (20)	6.2 (380)	calculated
- water heater	2.3 (5)	in H2O tank	catalogue
- air heater	2.3 (5)	2.5 (150)	rough estimate
Powered mechanisms:			
- pumps	23 (50)	5.1 (310)	catalogue
- fans	2.3 (5)	0.8 (50)	catalogue
- motors	23 (25)	1.1 (70)	rough estimate
- VCDS/phase separator	52 (115)	145 (8870)	mod. exist. hrdwr

SYSTEM CHARACTERISTICS (CONT'D)

The total mass and volume of the components include a 25% design contingency factor.

The total dry mass of the Service Unit system including the rack, but no specimen chambers, is greater than the allowable launch mass for unreinforced payload racks. Therefore, for this design the Service Unit rack would need to include extra structural support. The total volume of all the internal components of the Service Unit, less rack structure, is approximately 3/4 of the available internal rack envelope.

MASS/VOLUME CHARACTERISTICS

SUBSYSTEM & COMPONENTS	DRY MASS	VOL	BASIS
	kg (lbm)	liters (in ³)	
Structure:			
- rack mass	61 (135)	-	Freedom supplied
- substructure, rotor, & shaft	61 (135)	442 (26980)	rough estimate
- plumbing, ducts, and insulation	54 (120)	66 (4040)	rough estimate
- cable	9.1 (20)	12 (710)	rough estimate
- tanks	4.5 (10)	70 (4250)	calculated
- wash modules	4.5 (10)	included w/rotor	calculated
Subtotal	366 (805)	861 (52550)	
25% Design Contingency	91 (200)	215 (13140)	rough estimate
TOTALS:	457 (1,005) ¹	1076 (65,690) ²	

(1) 114% of allowable launch mass without support

(2) 72% of estimated 90,700 in³ of usable rack volume

SYSTEM CHARACTERISTICS (CONT'D)

The following chart summarizes the estimates for electrical power required by the Service Unit. The estimates are based on Freedom supplied information, existing space flight hardware, calculations, and catalogue values. For each component, the method of thermal rejection is listed. For many items, coolant circulating through a cold plate provides a heat sink.

The peak power for the Service Unit is 1250 watts which occurs during the air dry phase. During this phase, an electric heater heats up the air, and several fans and pumps are operational. However, during the hours when the Service Unit is washing equipment and recycling water, the average power required is 400 watts. These estimates include a 25% design contingency.

POWER CHARACTERISTICS

SUBSYSTEM & COMPONENTS	OPERATIONAL POWER (W)	THERMAL REJECTION
Electronics:		
- Power Protection Assemblies(PPA)	45	coolant (via cold plate)
- power electronics	200	coolant (via cold plate)
- MDM/EDP	85	coolant (via cold plate)
- control panel	40	cabin air
Thermal Control		
- Immersion water heater	500	coolant, avionics air
- air heater	300	coolant
Powered mechanisms:		
- pumps	225	avionics air
- fans	215	coolant, cabin air
- lights	60	coolant, cabin air
- valves	40	avionics air
- motor	100	coolant (via cold plate)
- VCDS/phase separator	170	coolant

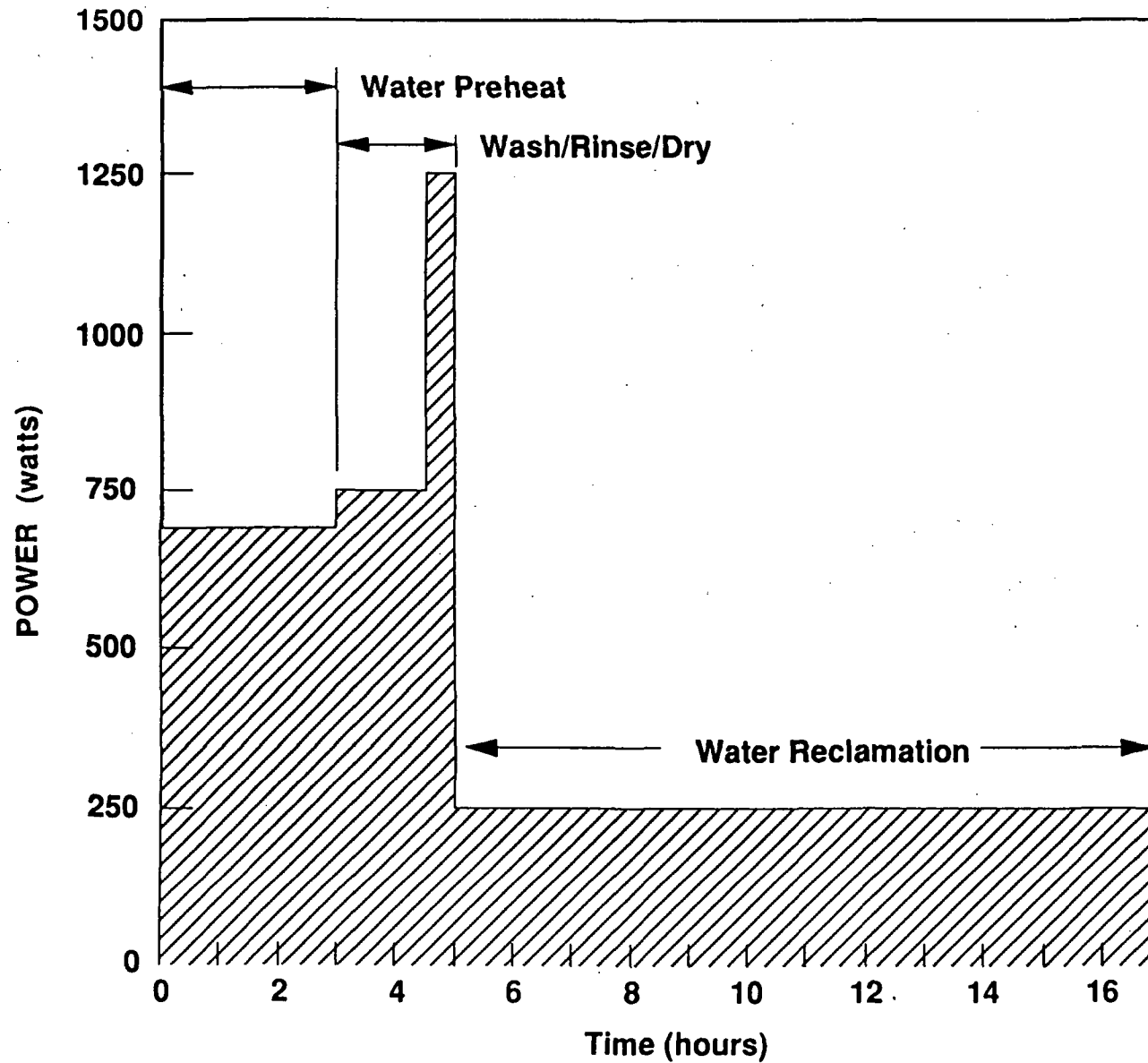
- Peak power: 1250 W (including 25% design contingency)
- Average power: 400 W over 17 hours (including 25% design contingency)

SYSTEM CHARACTERISTICS (CONT'D)

Because the Service Unit operates with multiple phases, the power consumed varies over time. Over a span of 17 hours, the Service Unit heats up the water (3 hours), washes and rinses the specimen chambers (100 minutes), dries the chambers (20 minutes), and then reclaims the water (12 hours). Power levels fluctuate because different components are active during the different phases.

Preheating the water requires 700 watts to drive the electric immersion heater and supporting electronics. The wash and rinse phases require 750 watts to drive pumps, the rotor, and necessary electronics. Peak power consumption occurs during the air dry cycle when 1250 watts are required. During this phase, fans, pumps, electronics, and a resistance heating element are powered. Water reclamation requires only 250 watts to operate the VCDS and supporting electronics. During the course of 17 hours, the average power required is 400 watts.

ELECTRICAL POWER PROFILE



SYSTEM CHARACTERISTICS (CONT'D)

Estimates of the consumables required by the Service Unit were made based on a projected number of 30 servicings in 90 days. These estimates are summarized on the following table.

The CRS canister is designed to be changed out once every 90 days. The filters found inside the wash modules and filter cartridges need to be changed more frequently. Based on engineering judgement, the gross particulate filter in each wash module would have to be replaced after every wash. These filters could be manually cleaned rather than replaced if crew time were available. The pair of water filter cartridges would also foul quickly and need to be changed approximately once every two wash loads. Since HEPA filters need to be changed only once a year, the stated servicing frequency is 1/4 per 90 days. However, the listed mass and volume are the amounts that would be required during one entire year.

The Service Unit also requires a small amount of detergent for each wash. Each time water is recycled, the feed water must be pretreated with a mixture of small amounts of oxone and sulfuric acid to control pH. Brine from the water reclamation is stored in a tank and must be periodically removed from the Service Unit. Make-up water must be supplied to support Service Unit operations because the VCDS is not 100% efficient in reclaiming water.

CONSUMABLES

Over a 90 day period, assuming 30 washings, the following items would need to be changed from the Service Unit:

ITEM	QUANTITY PER 90 DAYS	MASS lbm (kg)	VOLUME in ³ (m ³)
Vent CRS	1	15 (6.8)	620 (0.01)
Wash module filters	60	60 (27.3)	360 (0.006)
Water filter cartridges	30	150 (68.2)	15360 (0.25)
HEPA Filter*	1/4	5 (2.3)*	110 (0.002)*
Detergent/disinfectant	1	5 (2.3)	150 (0.002)
Waste water pretreatment additives	1	2 (0.9)	50 (0.001)
Brine	15	230 (104.6)	5500 (0.09)
Make-up water (hygiene quality minimum)	23 gallons	180 (81.8)	5200 (0.09)

*mass and volume are for 1 filter

INTERFACES

The crew interfaces with the Specimen Chamber Service Unit via a slide out control panel. The control panel is an electroluminescent touch panel display that can display multiple menus. The electroluminescent screen can also be used to display parameters important for monitoring the activity of the Service Unit. Because of the limited frontal rack area, the control panel must be pulled out for use.

A pair of hinged covers conceal the rotor when it is spinning. It protects the crew from the visual confusion and safety hazards created by the rotor motion. When the wash modules or filter cartridges need to be accessed, the rotor is stopped and the covers opened.

USER INTERFACE

- Operations controlled from slide out control unit
- Control unit contains a touch screen panel
- Hinged covers conceal moving rotor
- Covers can not be opened unless rotor is completely stopped
- Once rotation of the rotor stops, wash modules can slide out and be moved to the Life Sciences Glovebox for handling of the specimen chambers

INTERFACES

The nominal heat rejection by the Service Unit is expected to be 750 watts, corresponding to the wash and rinse phases of the Service Unit load cycle. In this mode, 650 watts is rejected into the 4°C coolant loop via a water-to-water heat exchanger. The remaining energy is dissipated into the avionics or cabin air. During the peak power load of 1250 watts of the air dry phase, 1105 watts is removed by the 4°C coolant loop and 145 watts by the cabin. These are the peak heat rejection loads that Freedom should see. The peak avionics air heat rejection load would occur during the wash and rinse phases, and is equivalent to the average air heat rejection load.

The Service Unit will generate low rate engineering data from all the sensors that monitor its activity. These data can be accessed by the Freedom data system if desired. However, it is unlikely that there is any need to monitor the system during normal operations.

The Service Unit will need to interface with the PMMS portable glovebox to support transport of the brine containers. However, no information about the portable glovebox had been received at the time this report was written, so the exact interface to the glovebox is undetermined.

FREEDOM INTERFACES

- Electrical power system:
 - 700 W for 3 hours of water preheating
 - 750 W for 100 minutes of washing and rinsing
 - 1300 W for 20 minutes of air drying
 - 250 W for 12 hours of water reclamation
 - 400 W average over 17 hours
- Heat rejection loads

	Nominal	Peak
- 4°C coolant loop	650	1105
- Avionics air	50	50
- Cabin air	50	145
- Data:
 - 12.4 Kbps engineering data to local data bus
 - 0 Kbps science data
- PMMS Glovebox: TBD interface
- Caution/Warning system: TBD interface
- Fire suppression system: TBD interface

TRADEOFFS

To develop the Service Unit reference design, a number of tradeoff studies were performed to evaluate the different design options. The different options and their respective merits are covered in the following pages.

In each study, several options are reviewed. The option is listed at the top of each column. Advantages of the option are preceded by a "+", and disadvantages are preceded by a "-". Items that are neither advantageous or disadvantageous are preceded by a "o". The "+, -, o" notations are qualitative and should not be tallied to determine quantitative measures of merit.

Based on the relative merits of each tradeoff, a selection was made. This selection is listed on the bottom of each tradeoff, within the box labelled "current choice." The label indicates that this is the present baseline option selected. However, information is still being gathered and the choice could change after future studies are completed.

TRADEOFFS

The following are a list of tradeoffs made during this study

- Washing Method
- Water Temperature
- Equipment Transfer Method
- Filter Maintenance
- Water Reclamation Method
- Distillation Technology
- Washing vs Disposing of specimen chambers

TRADEOFFS (CONT'D)

Assuming that the specimen chambers will be cleaned rather than disposed of, numerous techniques can be used for cleaning chambers.

Ultrasound is a relatively new and unproven method for cage washing. But studies have shown that it does not clean effectively and requires a high power level. Although sterilization is not a requirement, the ability to sterilize equipment would be an advantage. It is doubtful that ultrasound can be used to sterilize large specimen chambers. Moreover, the need to immerse equipment within a liquid bath poses additional fluid handling problems associated with a microgravity environment.

Water washing is the most widely used cleaning technique, and it achieves a high degree of cleanliness. Washing for sanitization requires only moderate levels of power, but sterilization would require much greater power. Another disadvantage of this method is the need for special water handling equipment suitable in a zero-g environment.

Baking of the specimen chambers is a cleaning method that reduces water consumption. Furthermore, specimen chambers could be sterilized with this method. However, like ultrasound, it has a high power requirement. In addition, the associated high temperatures are a safety concern.

After surveying the different methods, water washing was selected as the baseline method. It's the most proven of the three methods, and requires the least amount of power to achieve the minimum cleaning and sanitization standards.

WASHING METHOD

Ultrasound	Water Washing	Baking
<ul style="list-style-type: none">- Poor cleaning effectiveness- High power consumer+ Low impact on specimen chamber design- Not suitable for sterilization	<ul style="list-style-type: none">+ High cleaning effectivenesso Moderate power consumer+ Low impact on specimen chamber design- Not suitable for sterilization	<ul style="list-style-type: none">+ Good cleaning effectiveness- High power consumer- High impact on specimen chamber design+ Suitable for sterilization

Current Choice: Cleaning with water is the most effective and energy efficient method to clean and sanitize specimen chambers

TRADEOFFS (CONT'D)

The water temperature for water washing should be optimized for the function and operation of the Service Unit. In general, hot water will destroy more microorganisms than cold water. However, the energy required to heat the water increases the electrical power required.

Many washing studies reference a milk pasteurization process approved by the National Sanitation Foundation (NSF) as a standard. This method uses a calculated temperature and time dependent value to determine if sanitization has been achieved. A minimum temperature of 143°F must be achieved to reach an acceptable level of cleanliness. Tests with specimen chamber coupons show that the coupons can be cleaned down to 50 CFU/100 cm² to reach the sanitization level, as defined by NSF. These results provide a strong argument for using heated water.

If the 50 CFU/100 cm² limit is relaxed as a requirement, hot water is unnecessary. Cold water may be acceptable for cleaning plant chambers as there is less of a concern over microorganisms. Cold water may also be used if a suitable chemical disinfectant is found to destroy microorganisms to the desired cleanliness level.

The baseline Service Unit design can be used with either hot or cold water. A heater is provided to warm up the water to the desired temperature, but it can be shut off when not needed. The baseline washing method uses a combination of hot water and chemical disinfectant to meet the surface cleanliness requirement.

WATER TEMPERATURE

Hot Water	Cold Water
<ul style="list-style-type: none">+ Capable of sanitization- Increased electrical power required- Increased thermal output+ Low amount of chemical additives required	<ul style="list-style-type: none">- Will not sanitize+ Decreased electrical power required+ Decreased thermal output- High amount of chemical additives required

Current Choice: To provide sanitization capability of the Service Unit, hot water is used for washing

TRADEOFFS (CONT'D)

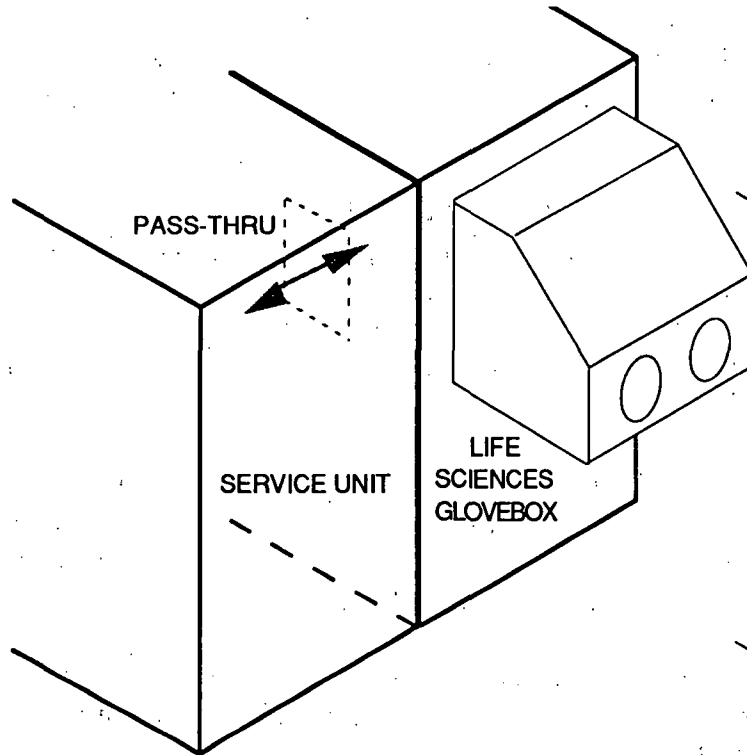
Bioisolation must be maintained while transferring specimen chambers into and out of the Service Unit. The soiled specimen chambers cannot contaminate the cabin, the cabin cannot contaminate the clean specimen chambers, and dirty chambers cannot contaminate the clean chambers.

Three possible means of accommodating equipment transfers were studied. The three options are illustrated on the next page and are described on subsequent pages.

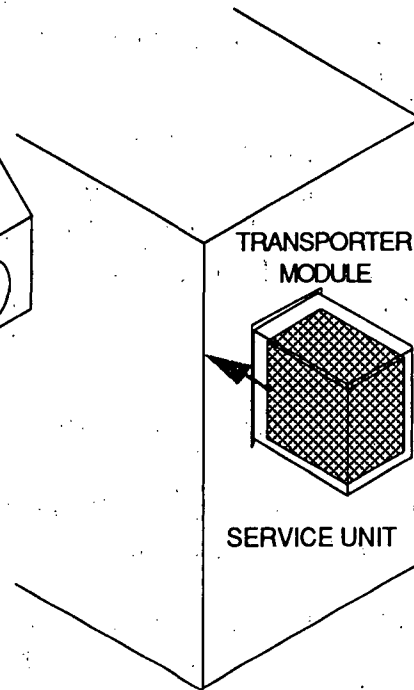
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EQUIPMENT TRANSFER METHODS

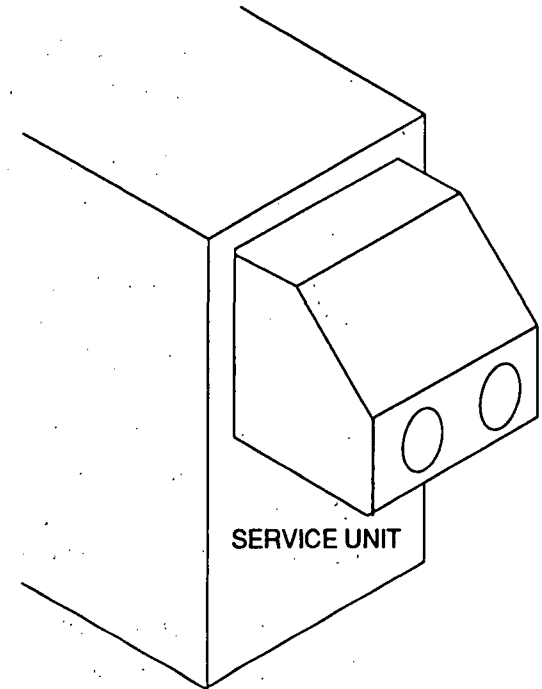
**PASS-THROUGH
FROM LIFE SCIENCES GLOVEBOX**



**TRANSPORTER
MODULE**



**GLOVEBOX ON
SERVICE UNIT**



TRADEOFFS (CONT'D)

One approach to facilitate bioisolation is to rely on a pass-through from the Life Sciences Glovebox. In such a configuration, the Service Unit and Glovebox would share a common wall, and have a door cut through the wall for equipment exchange. This method requires that the Service Unit and Glovebox be adjacent to each other, which may be impractical. If either rack system must be tilted down for servicing, both racks would need to be rotated. This configuration also violates the front access requirement for the Service Unit.

The Life Sciences Glovebox can also be used for chamber servicing without a direct passageway to the Service Unit. To move chambers between the racks, a Habitat-like transporter module would be used. This would facilitate bioisolation by limiting handling of specimen chambers to the Life Sciences Glovebox. However, all methods which use the Glovebox increase the operational burden of the Glovebox. This method would satisfy the front interface requirement without incorporating a glovebox within the Service Unit.

Duplication of the Life Sciences Glovebox environment may be done at the Service Unit. Because there is limited space, the Service Unit glovebox should be a compact system with a collapsible work volume. However, a fully operational and bioisolated glovebox system requires extensive volume allocation for fans and filters, space that is not available inside the Service Unit rack.

Of all the options reviewed, development of a special modular carrier seems to be the optimal choice. This module can act as a transporter between the Service Unit and Life Sciences Glovebox, and can contain some of the hardware to wash the specimen chambers.

EQUIPMENT TRANSFER

LSG Pass Thru	Modular Carrier	SCSU G/B
- Does not meet front access requirement	+ Meets front access requirement	+ Meets front access requirement
+ Minimal volume impact	+ Minimal volume impact	- Volume required for G/B subsystems
- Impacts LSG design	+ No impact on LSG	+ No impact on LSG
+ Minimal crew time required	- Crew time required for carrier transport	- Crew time required for Habitat transport
- Increased operational burden of LSG	- Increased operational burden of LSG	+ Decreased operational burden of LSG
+ No intrusion into aisle	+ No intrusion into aisle	- Temporary intrusion into aisle may require waiver
- Complicates on-orbit assembly	+ No on-orbit assembly complications	+ No on-orbit assembly complications
- Limits location of SCSU and LSG	+ No limit on location of SCSU and LSG	+ No limit on location of SCSU and LSG

Current Choice: A Service Unit unique carrier module is the one option that meets the front access requirement with minimal volume impact. In this design, the wash module doubles as the specimen chamber carrier module.

TRADEOFFS (CONT'D)

Water washing requires that solid particles be removed from the water. The large quantities of solid waste matter (e.g. hair, leaves, undissolved food) removed from the specimen chambers and waste trays portends problems with clogged water lines.

Filtering the water would solve the problem. Filters that can be back-flushed, such as flat plate filters, would prevent clogs and would not need to be changed. However, the particles that are back-flushed must still be removed, inferring that another filter is required to trap the particles.

Disposing of filters before they clog is another solution. However, filters clogged with hair and other solid matter may require replacement after each wash. Such expendable filters would incur additional costs in storage space and transport to/from orbit.

Mechanical shredders, similar to kitchen sink garbage disposals, are in use in water treatment plants and zoos to grind solid matter in fluid lines. Shredders are most effective in pulverizing large particles that may obstruct pipe flow. However, buildup of the resulting smaller particulates poses a problem downstream of the shredder, increasing the likelihood of clogging fine mesh filters. Shredders also incur a weight, power, and volume penalty.

The only system that completely handles solid particulates are filters. Using a series of coarse and fine particulate filters would reduce the frequency of filter replacement as well as the risk of having blocked water pipes.

FILTER MAINTENANCE

Back-flush Filter	Disposable Filters	Mechanical Shredder
- Back-flushed waste matter must be handled downstream	+ No further processing required	- Resulting particulate matter must be handled downstream
- Clogging possible up/downstream	+ Reduced chance of clogging	+ Reduced chance of clogging
+ No chance of breakdown	+ No chance of breakdown	- Chance of breakdown
+ No power required	+ No power required	- Power required
+ No storage space required except for back-flushed-waste	- Storage space required for filters	+ No storage space required except for particulate matter
+ No logistics costs except for back-flushed waste	- High logistics costs	+ No logistics cost except for particulate matter
- No extra crew time required	- Filter changeout requires crew time	- No extra crew time required
+ No additional acoustic and mechanical disturbances	+ No additional acoustic and mechanical disturbances	- Source for acoustic and mechanical disturbances

Current Choice: Disposable filters are the best way of minimizing clogs from animal hair and other waste matter in the water flow.

TRADEOFFS (CONT'D)

Cleaning the specimen chambers will require 7.5 gallons of clean water for each wash load. If this water is not recycled, the stowage and logistics penalty will be prohibitive.

There are 2 basic types of water reclamation systems being evaluated for Freedom use. Distillation is a mechanical system that relies on a phase change in water to separate it from the impurities. Reverse osmosis (RO) relies on osmotic pressure differentials to remove solute from waste water.

For water containing a high concentration of solid waste matter, reverse osmosis systems are less efficient and more prone to clogging than distillation systems. Clogging is gradual in RO membranes, but eventually, the membranes must be either back-flushed and cleaned, or replaced. For the purposes of this study, the membranes are assumed to be replaced, thus incurring a large logistics and stowage penalty. Because of the higher efficiency and lower expendables required by distillation technology, it is the preferred means for water reclamation.

WATER RECLAMATION

Distillation

Reverse Osmosis

- | | |
|---------------------------------|-----------------------------------|
| + Low expendables | - High expendables (filters) |
| + 90-95% water recovery rate | - 80-90% water recovery rate |
| - High power required | + Low power required |
| - Prone to mechanical breakdown | + Fewer mechanical components |
| - Time required for maintenance | - Time required for filter change |

Current Choice: The higher recovery rate and fewer expendables required by distillation reduces the logistics and storage costs and offsets the greater power requirement.

TRADEOFFS (CONT'D)

There are two different distillation systems being considered for use onboard Freedom. The two systems are TIMES (Thermoelectric Integrated Membrane Evaporation Subsystem) and VCDS (Vapor Compression Distillation Subsystem.)

TIMES relies on the warm side of a thermoelectric unit to heat up the waste water. The water is pumped through a wick module, evaporates, and then condenses at the cool side of the thermoelectric unit. The wick module is relatively large and the thermoelectric unit is a high power consumer.

VCDS has a rotating double-walled drum with dirty water circulating within the inner section. A lobe compressor draws vapor from the inner region of the drum and pumps it to the outer section of the drum. In doing so, it increases the pressure of the vapor, allowing the vapor to condense at the wall separating the inner and outer sections. The latent heat is transferred to the water in the evaporation section of the drum and the condensate is pumped out from the outer section. Overall, it requires little external energy input, but it has questionable mechanical reliability.

The comparison of the two systems shows that VCDS is superior to TIMES in size, mass, and power required. Although the VCDS may be more prone to breakdown, this is acceptable because the Service Unit will not be recycling water continuously. It will have frequent scheduled down times when any internal component or system can be serviced.

DISTILLATION TECHNOLOGY

TIMES - Thermoelectric Integrated Membrane
System

VCDS - Vapor Compression Distillation System

- | | |
|--------------------------|----------------------------|
| - High power consumption | + Low power consumption |
| - High volume | + Low volume |
| - High mass | + Low mass |
| + Good reliability | - Questionable reliability |
| + High efficiency | + High efficiency |

Current Choice: VCDS requires less volume, mass, and power, while recovering more water than TIMES.

TRADEOFFS (CONT'D)

Although one of the ground rules of this study is to assume the Service Unit would be a washer system, disposing of the specimen chambers was investigated as an option. This was done as an exercise to evaluate areas for future development work.

The primary advantage of having a washer system is the capability to wash a large variety of equipment besides specimen chambers. This makes the Service Unit a multi-user hardware system shared by many disciplines. An alternative would be to dispose of every piece of soiled equipment, incurring a large logistics and stowage penalty.

Alternatively, if the system was limited to only servicing specimen chambers, a tradeoff may support using disposable chambers. The volume required for an entire collapsible or stackable specimen chamber is only slightly more than that for a waste tray liner (which is disposable in the baseline Habitat design.) The time required for changing a waste tray liner will be approximately equal to the time to change an entire specimen chamber, but no extra time will be required to operate a washer. For this reason, it may take less crew time to replace rather than wash specimen chambers depending on whether or not assembly is required for disposable specimen chambers.

A disposable system requires less power and water, is not prone to breakdowns, does not have a rotating device to generate mechanical disturbances, and requires minimal technology development. However, onboard storage is required and some onboard assembly of specimen chambers may be required. Some on orbit power may be required if a trash compactor must be used. Disposable chambers are also attractive because they can be sterilized on the ground, hermetically sealed, and available in sterile condition for on orbit experiments.

If there is no washer system, items that would normally be washed between uses (e.g. bottles, tools, etc.) would need to be disposable. The overall logistics and stowage costs of this option must still be determined. This is one of several issues that must be addressed before a final recommendation on this trade-off can be made. Preliminary analysis shows that disposing rather than washing specimen chambers has many important advantages. Therefore, disposable specimen chambers merit further study before a configuration for the Service Unit can be chosen.

WASHING VS DISPOSING TRADEOFF

Washing of Chambers

- + Can clean many different items
- + Can be used by others
- More power required
- More water required
- More crew time required
- Stowage for waste tray liners, replacement parts, brine, detergent
- Source of mechanical disturbances
- Questionable reliability
- Requires technology development
- Sterilization requires high power
- Thermal energy output
- More crew time for maintenance

Disposing of Chambers

- All items must be disposable
- Other users may require washer
- + Less power required
- + Less water required
- + Less crew time required
- Stowage for specimen chambers
- + No mechanical disturbances
- + High reliability
- + Minimal technology development
- + Sterile chambers can be provided
- + Less thermal energy output
- + Less maintenance

Current Choice: Baseline configuration is a washer; disposing of the chambers is an attractive alternative that merits further study

SCHEDULING

Two representative life science experiments were selected to identify operational concerns for specimen chamber servicing. One rodent and one plant experiment were chosen. No squirrel monkey experiment was selected because squirrel monkeys are not expected to be flown till the later stages of the research program.

The rodent experiment focuses on myocardial, muscle, and neurosensory changes due to adaptation to microgravity. It also provides insight into the synergistic effects of weightlessness and radiation on the selected tissues. The plant experiment attempts to discover the way plants sense gravity and transmit this information to all parts of the plant. The study also looks at gravity's effect on plant development, and the role gravity plays in regulating metabolic processes.

These two experiments are representative of on-orbit experiments. However, their selection here does not indicate that they are the experiments that are likely to be selected for actual spaceflight.

SCHEDULING BASELINES

Baseline Experiment: Study of myocardial, muscle, and neurosensory changes and synergism of weightlessness and radiation in rodents

- 48 young adult male rats (12 Habitat equivalents)
- 6 Habitats located at the Centrifuge, 6 Habitats located at the Holding Unit
- 40 rats sacrificed at different intervals
- 1 rat sacrificed per Habitat
- Specimen chamber servicing occurs at regular intervals
- No squirrel monkeys included in baseline

Baseline Experiment: Multiple generation plant growth

- 4 Plant Habitats
- Specimen chamber servicing occurs after harvesting of plants

SCHEDULING

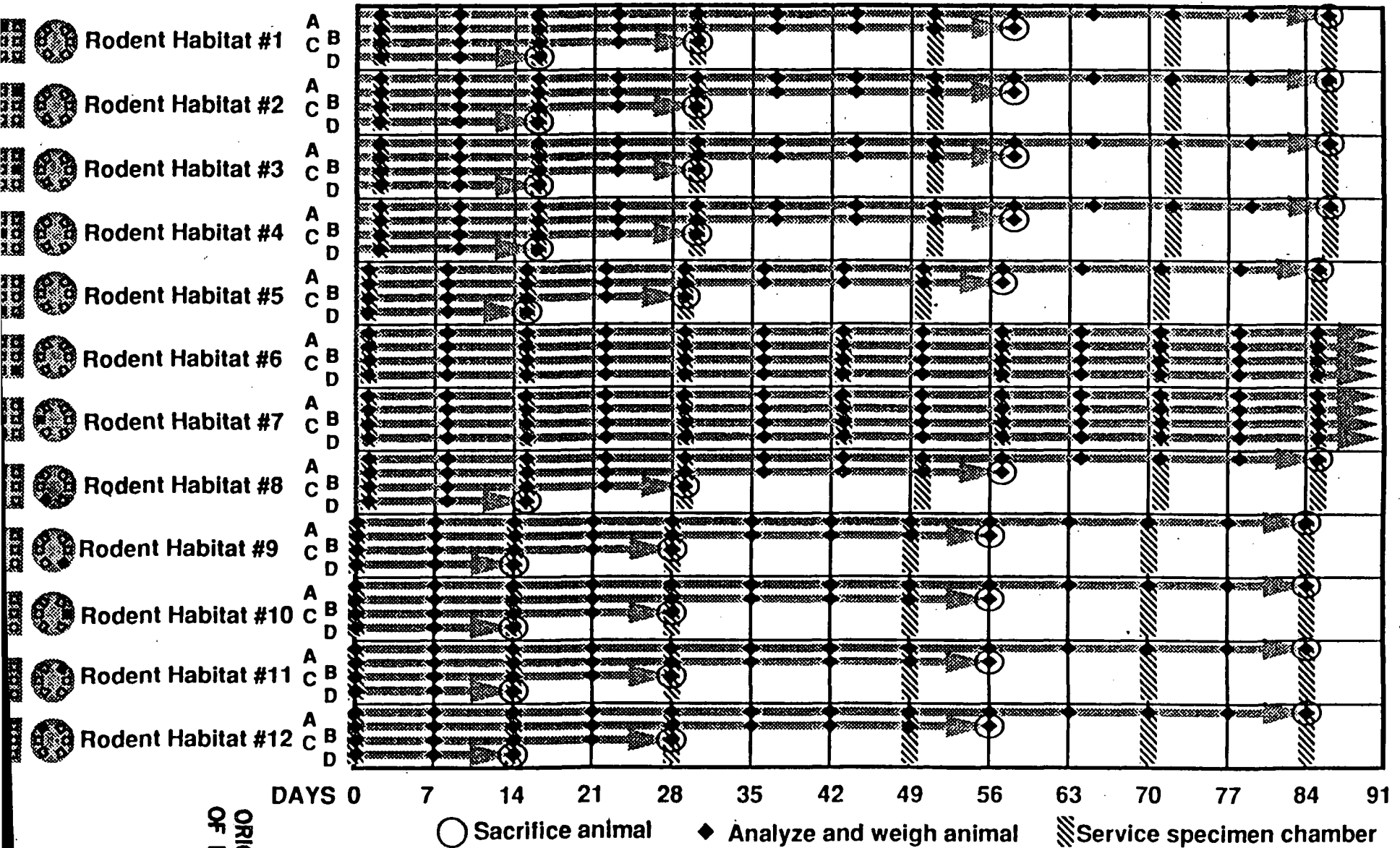
The following chart summarizes crew handling operations for the rodent experiment previously defined. The 12 rodent Habitats are used continuously during much of the 90 days. Each Habitat contains four rodents. Six of the twelve Habitats are housed on the Centrifuge, while the other six reside in the Holding Unit. It was assumed that no more than 4 Habitats can be worked with each day due to scheduling and crew time constraints. In the chart, each row represents a Habitat and each of the 4 arrows in each row represents a rat. The black diamonds indicate health checks of the animals, when the rodents are weighed and analyzed at the Life Sciences Glovebox. A circle around the diamond indicates that the rat is sacrificed for analysis. Rats are sacrificed after approximately 2, 4, 8, and 12 weeks. In total, 40 are sacrificed over the experiment duration and 8 are kept alive.

Cross hatched rectangles represent servicings of the rodent specimen chambers. Servicings occur no oftener than every 14 days. In Habitats where rodents are sacrificed, servicing intervals increase because chambers become soiled at a slower rate. Chambers are washed at the beginning of the 90 day period because they are assumed to be soiled from earth-to-orbit flight, and are washed after the last rodent in the chamber is sacrificed. Four chambers are serviced in one load, and no more than one load is run in one day.

No equivalent chart is presented for the plant scenario. Scheduling for plant chamber servicing is more straightforward than for the rodents. The plant chambers need to be cleaned only at the beginning and at the end of the 90 day period.

SERVICING SCHEDULE

SERVICING AND GLOVEBOX SCHEDULE IF ANIMALS SACRIFICED FROM DIFFERENT HABITATS



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SCHEDULING

Assuming the baseline approach to rodent experiments is to sacrifice no more than one individual rodent per Habitat, there would be 17-21 wash loads per 90 days. There would be an additional 4 loads of plant chambers, 2 at the beginning and 2 at the end of the 90 days. If another 5 loads of other equipment are washed, a worst case scenario of 30 washings over 90 days is expected. This implies that the Specimen Chamber Service Unit will not be operating every day. In fact, the Service Unit will be inactive more than it will be active while it is onboard Freedom. It is unlikely that the Service Unit would ever be needed to wash items more than once a day.

Because this baseline design of the Service Unit relies on the Life Sciences Glovebox for specimen chamber and equipment transfers, the two system's operating schedules must be coordinated. Since the Glovebox is likely to be the more highly subscribed of the two systems, its scheduling will determine Service Unit scheduling.

SCHEDULING

Summary:

- 17-21 loads of rodent specimen chambers per 90 days
- 4 loads of plant specimen chambers per 90 days
- 5 loads for cleaning equipment other than specimen chambers
- Worst case baseline: 30 servicings per 90 days
- Life Sciences Glovebox and Service Unit operations are interdependent

REQUIREMENTS NOT MET

The current baseline Service Unit concept meets the majority of the science and functional requirements. However, there are two requirements that are not met. The Phase B Specifications requires that all hardware maintain two levels of bioisolation at all times, including filter changeout. The Service Unit violates this requirement for brief periods of time during filter replacement operations. Small areas of contaminated surfaces are exposed to the cabin environment before a double walled bag is placed around them.

The wash modules are double walled to provide one fault tolerance biocontainment. The phase B specification requires two fault tolerance biocontainment.

REQUIREMENTS NOT MET

The following requirements have not been met by the current concept:

- Maintain two layers of bioisolation during filter change out
- Maintain two fault tolerance biocontainment during on-orbit transport in wash module

FURTHER STUDY

It cannot be stated that all requirements have been met without actual hardware. This is especially true for the cleanliness standards established for the Service Unit. Only tests with washer hardware can determine if the specimen chambers can be cleaned to the desired levels.

The satisfaction of several requirements is a function of hardware design and crew operations. This includes all requirements involving maintenance and bioisolation. For example, requirements state that items which require servicing, such as the Service Unit CRS canister will need to be changed within a 30 minute period. The CRS canister is located at the rear of the rack, where there is direct access once the rack is pulled down and the rear panels removed. However, it's not possible to determine if the 30 minute requirement can be met until the actual canister replacement procedure is defined and tried.

FURTHER STUDY

Hardware tests are required to determine if the following requirements are met:

- Vibration & acoustic noise limitation
- Cleanliness level of items washed
- Removal of all chemical residues

Satisfaction of the following requirements depends partly on the development of suitable operations:

- Bioisolation
- Cleanability and sanitization
- Maintenance

FURTHER STUDY (CONT'D)

There is a strong need to quantify cleanliness standards. Presently, the Phase B specifications define a cleanliness standard of 50 Colony Forming Units/100 cm². According to the Science Working Group, this standard should be adequate, and is perhaps more stringent than necessary. However, a diverse group of scientists plan on using the Service Unit to support their experiments, and the cleanliness standard must satisfy all of them. Therefore, further study is required.

This study used 2 specific science experiments to develop an operational baseline. There are many other experiments that will use the Centrifuge Facility, and it is important that they be evaluated in terms of operational requirements of the Service Unit. Since the Service Unit relies on the Life Sciences Glovebox for equipment transfers, operational impacts to the Glovebox from servicing operations must also be determined. Overall, operations must be developed that reduce the amount of crew time required.

Several Freedom interfaces are not defined in this report because of insufficient information. More investigations must be undertaken to understand the Freedom interface requirements for the PMMS portable glovebox and the fire detection and suppression system.

FURTHER STUDY (CONT'D)

Cleanliness Definition

- Evaluate acceptability of present cleanliness specification for wide range of users

Operations

- Determine frequency of servicing required for different specimen chambers and experiment protocols
- Evaluate impact of Service Unit operations on Life Sciences Glovebox operations
- Optimize operations to reduce crew time required

Interfaces

- Gather more information describing the PMMS portable glovebox, fire detection and suppression system, and caution/warning system to design the appropriate interfaces

FURTHER STUDY (CONT'D)

The information used to select a water reclamation system was derived from studies of Freedom ECLSS technologies. Comparative testing of the TIMES and VCDS systems is planned at Marshall Space Flight Center; the results of the testing will help determine if VCDS is the appropriate selection for the Service Unit. As the tests proceed, Ames will monitor them to stay abreast of the latest information.

Regardless of the technology, water reclamation is facilitated by chemically treating the waste and product water. At a minimum, the treatments reduce microbial growth. Treatments may also process the water to a higher quality. Presently, a small amount of oxone and sulfuric acid is used to pretreat the water to control pH and microbial growth. The effectiveness of this method must be verified, and post-treatment methods must be evaluated.

The systems being considered have not been comprehensively tested for their ability to handle used wash water. This is an important determinant that needs more research. The current Service Unit design assumes that water will be recycled to hygiene quality water. The standard for hygiene water is deemed satisfactory for human washing, yet its compatibility with animal and plant chamber washing has not been determined. It is possible that lower quality water may be acceptable for washing as long as the chamber cleanliness standards are ultimately met.

While active, the Service Unit rotor and pumps will be rotating, thereby generating a level of mechanical disturbance. This level must be determined, and then, if necessary, methods to counteract these disturbances must be identified and implemented. The use of multiple filters must also be evaluated. In addition, the number and fineness of the filters must be established.

FURTHER STUDY (CONT'D)

Water Reclamation

- Update information describing capabilities and limitations of the TIMES and VCDS technologies
- Improve understanding of pre- and post-treatment required for reclamation of water
- Evaluate ability of existing water reclamation systems to process water produced from chamber washings
- Define minimum water quality standards for washing

Mechanical Disturbances

- Refine analysis of mechanical disturbances generated by the Service Unit

System Reliability and Maintenance

- Evaluate use of multiple filters to prevent fouling of the water handling systems

FURTHER STUDY (CONT'D)

One trade-off study documented in this report demonstrated that specimen chamber disposal, rather than washing, is a viable method. But before such a configuration can be selected, many factors have to be evaluated. An equipment washer system is being considered for Freedom. Life sciences would be the primary user of the system, while other scientific disciplines might also use it. If a washer were not provided, the ramifications to the potential users would need to be identified.

From a Facility standpoint, if disposable specimen chambers are desired, the designs of the chambers must be optimized to facilitate replacement. The designs of the chambers influence their packing efficiency when stored in bulk. This, in turn, affects stowage and logistics costs. The overall costs to store and transport consumables in both the disposing and washing options must be compared.

There are also concerns about end-to-end costs of either method. The costs incurred during development to full operation must be estimated to determine which one is less expensive. Disposables may be better for certain situations, while washing is preferred in others. This may lead to a combination of washing and replacing of specimen chambers. Another possibility is to have a phased program whereby chambers are initially disposed of, but later in the program, a washer is used to service the chambers.

One major concern of life scientists is the impact that non-life science users will have on the washer. Chemicals that are hazardous to the specimens may be introduced into the Service Unit by non-life science users. These chemicals may jeopardize experiments and render the Service Unit unusable. This potential problem may be avoided by banning substances that could adversely affect life science experiments.

FURTHER STUDY (CONT'D)

Disposing of specimen chambers

- Determine impact on Space Station if Service Unit washer configuration is removed from baseline
- Optimize design of specimen chambers for disposal
- Calculate stowage requirements for plant and animal chambers for baseline experiments
- Determine logistics and stowage costs of washing and disposing of specimen chambers
- Evaluate long term implications and end-to-end costs of disposing of chambers
- Evaluate disposal/washing combinations

Other Users

- Determine the needs of non-Centrifuge Facility users of the Service Unit
- Evaluate the impact of non-Centrifuge Facility users on Service Unit operations, water reclamation, etc.

TECHNOLOGY DEVELOPMENT

The water reclamation systems being evaluated are designed to provide hygiene and potable water for crew use. They are scaled to fit inside half of a standard rack. The space available in a Service Unit is smaller, requiring that the reclamation unit be redesigned or repackaged to fit.

An active system to compensate for the mechanical disturbances generated by the Service Unit may be required. Such a system may be very similar to the mass balancer used on the Centrifuge. Mass balancing is a topic to be addressed in detail for the Centrifuge; the results of that investigation will be useful for the Service Unit.

Another important Centrifuge component, the rotary joint, will have direct application to the Service Unit. The primary difference between the two applications is that the Centrifuge will have to transfer more data, electrical power, and liquid coolant across the joint. This means that the Centrifuge unit joint will be larger and more complex than that of the Service Unit, although the two could be similar in their basic design.

TECHNOLOGY DEVELOPMENT

Water Reclamation

- Optimize water reclamation systems for use with the Service Unit

Mechanical Disturbances

- Develop systems to reduce mechanical disturbances generated by the Service Unit

Rotary Transfer Joint

- Develop a rotary joint that allows for the transfer of water, air, data, and power

SUMMARY

The general finding of this study is that the majority of the requirements for the Specimen Chamber Service Unit can be met with the current design concept. The baseline configuration is a hot water washer system requiring the full use of a 74.5 inch rack. The majority of the rack volume is occupied by the rotor and the water reclamation system. The performance of the latter system determines the maximum frequency of use of the Service Unit. Whenever the Service Unit is used, the Life Sciences Glovebox must also be available for specimen chamber transfers.

The Service Unit can operate daily, but should be needed on the average only once every three days. The Service Unit can support daily operations because of the currently expected performance of the VCDS. The major reason a water reclamation system is incorporated into the design is to reduce the amount of consumables required. However, in this baseline Facility configuration, the specimen chambers have disposable waste tray liners, and the Service Unit requires a large number of disposable filters. Because many consumables are required, disposable specimen chambers are an attractive alternative worth more detailed study.

SUMMARY

Findings of the Service Unit study:

- Most major science and functional requirements are met with this washer concept
- Satisfaction of the requirements will require full use of the internal volume of a rack
- Operations of the Service Unit and Life Sciences Glovebox are interdependent
- Service Unit usage will be dependent on the capability and reliability of the water reclamation system
- The Service Unit will require a large quantity of filters and makeup water
- Disposing of specimen chambers is a viable alternative to washing that must be further evaluated

APPENDIX

BACK OF SUMMARY CHART

APPENDIX

- **SACRIFICE SCHEDULE EFFECTS**
- **SQUIRREL MONKEY SPECIMEN CHAMBER SERVICING REFERENCE PROTOCOL**

SACRIFICE SCHEDULE EFFECTS

The rodent experiment described earlier requires the sacrifice and dissection of rats at specific intervals. When several rats need to be sacrificed, they are selected individually from separate Habitats, rather than multiples from one Habitat. For example, 4 rats from the Centrifuge are sacrificed on the fourteenth day of the mission. Rather than selecting all 4 rats from one Habitat to be sacrificed, 1 rat from each of 4 different Habitats is chosen. This reduces the time that non-sacrificed rats must reside at the Glovebox. A dissection is a time consuming operation. If all the rats were chosen from one Habitat, one Habitat would be removed from the Centrifuge and brought over to the Glovebox where the rats could adjust to the gravity free environment until they are sacrificed. To avoid this, only one rat would be removed from each Habitat, so that Habitat could be immediately returned to the Centrifuge.

This approach impacts crew operations. If no more than one rodent per Habitat is sacrificed at any one time, then 64-84 specimen chambers (17-21 wash loads) are required. The variability is due to the variability in the servicing intervals as the number of rodents in the chambers decrease. If multiple rodents per Habitat are sacrificed, then 58-62 chambers (16-18 wash loads) are required. This approach reduces the power, water, and other expendables required by the Service Unit over 90 days. This would also reduce the number of times that Habitats are transported to and from the Glovebox for health checks, sacrifices, and specimen chamber transfer.

The purpose of this analysis is to highlight ramifications of different operational protocols. But to improve the science capabilities of the Centrifuge Facility, it is imperative that the needs of the science community be addressed. For this reason, the baseline experiment protocols call for one animal from each Habitat to be selected for sacrifice.

SACRIFICE SCHEDULE EFFECTS

- To limit the time of exposure to microgravity, the baseline experiment calls for one animal from each Habitat to be selected for sacrifice
- Alternative schemes may facilitate operations and reduce Freedom resource usage

Sacrifice 1 Rodent per Habitat

Sacrifice Multiple Rodents per Habitat
--

-
- | | |
|--|--|
| <ul style="list-style-type: none">• Animals from centrifuge are subjected to shorter periods of zero-g• 64-84 specimen chambers to service• 17-21 servicings: more power, make-up water, crew time required for servicings• Habitats must be transported to/from Glovebox 156 times: more crew time required to transport Habitats and to clean-up Glovebox | <ul style="list-style-type: none">• Animals from centrifuge are subjected to longer periods of zero-g• 58-62 specimen chambers to service• 16-18 servicing loads: less power, make-up water, crew time required for servicings• Habitats must be transported to/from Glovebox 112 times: less crew time required to transport Habitats and to clean-up Glovebox |
|--|--|

SERVICING SCENARIO

The servicing scenario is included here to illustrate how a typical specimen chamber washing operation may be performed with this Specimen Chamber Service Unit design. The procedure is preliminary; the actual protocol followed onboard Freedom may be different. However, it is presented here to highlight the steps that are required to bring specimens and materials in and out of the wash modules.

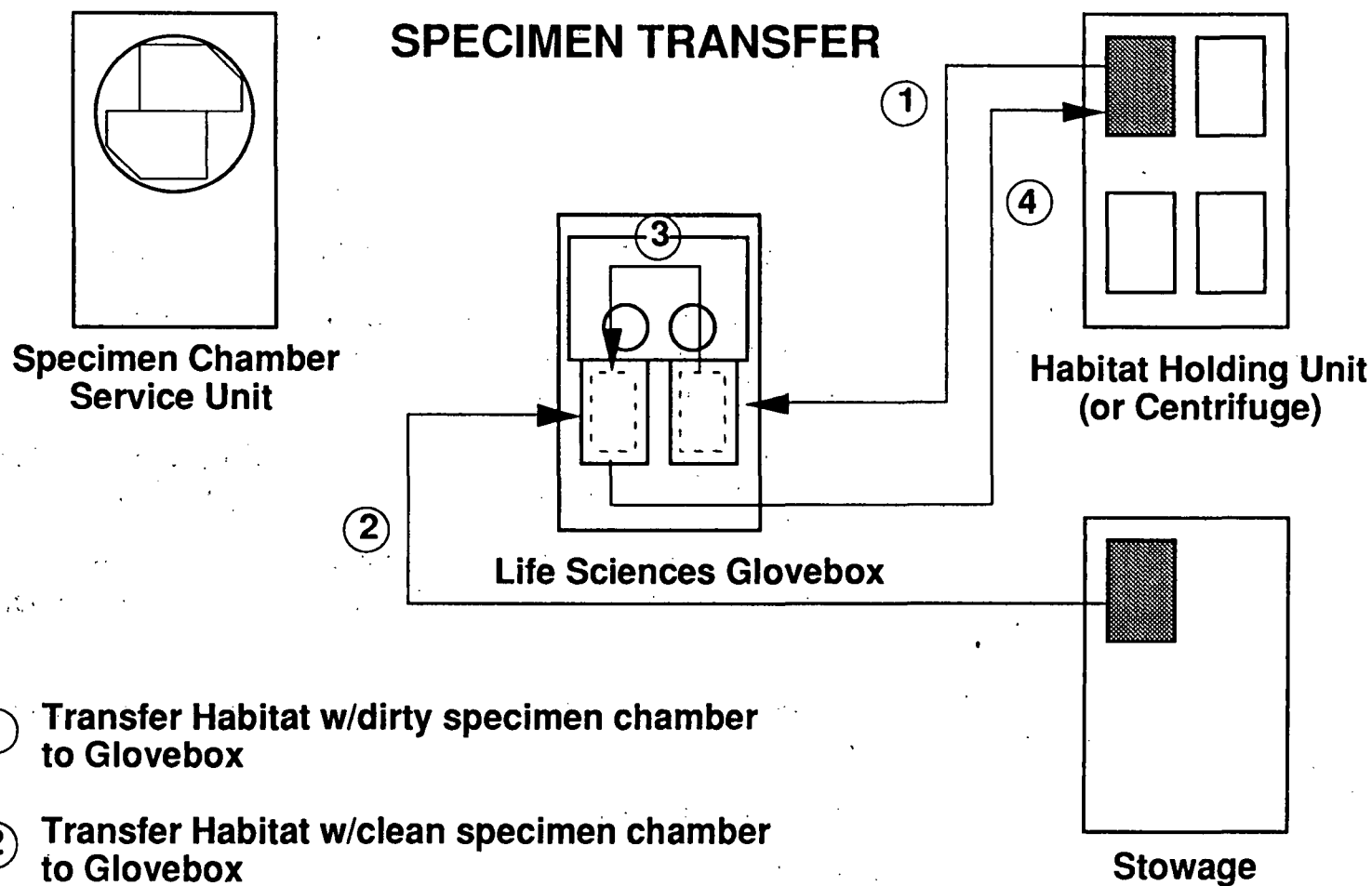
SERVICING SCENARIO

The following is a possible operations scenario for the servicing of an unrestrained squirrel monkey specimen chamber

1) Specimen Transfer

- i) Attach bag for trash storage to one of the 10 inch gloveports on the Glovebox
- ii) Remove habitat containing specimen chamber to be serviced from the Holding Facility; remove an unrestrained squirrel monkey habitat containing an empty, clean specimen chamber from its appropriate stowage area;
- iii) Transport both habitats to Life Sciences Glovebox; assuming Glovebox is activated and decontaminated, attach habitats to appropriate Glovebox/habitat interfaces;
- iv) Open outer and inner doors of the clean and dirty habitats; transfer animal from dirty specimen chamber to the clean one; some data collection may be performed during transfer process;
- v) Close door to the clean specimen chamber; wipe exposed surfaces of the clean habitat; close door to clean habitat;
- vi) Close doors to the dirty specimen chamber and habitat
- vii) Disconnect the clean habitat and transport it to the appropriate holding area;

SERVICING SCENARIO (CONT'D)



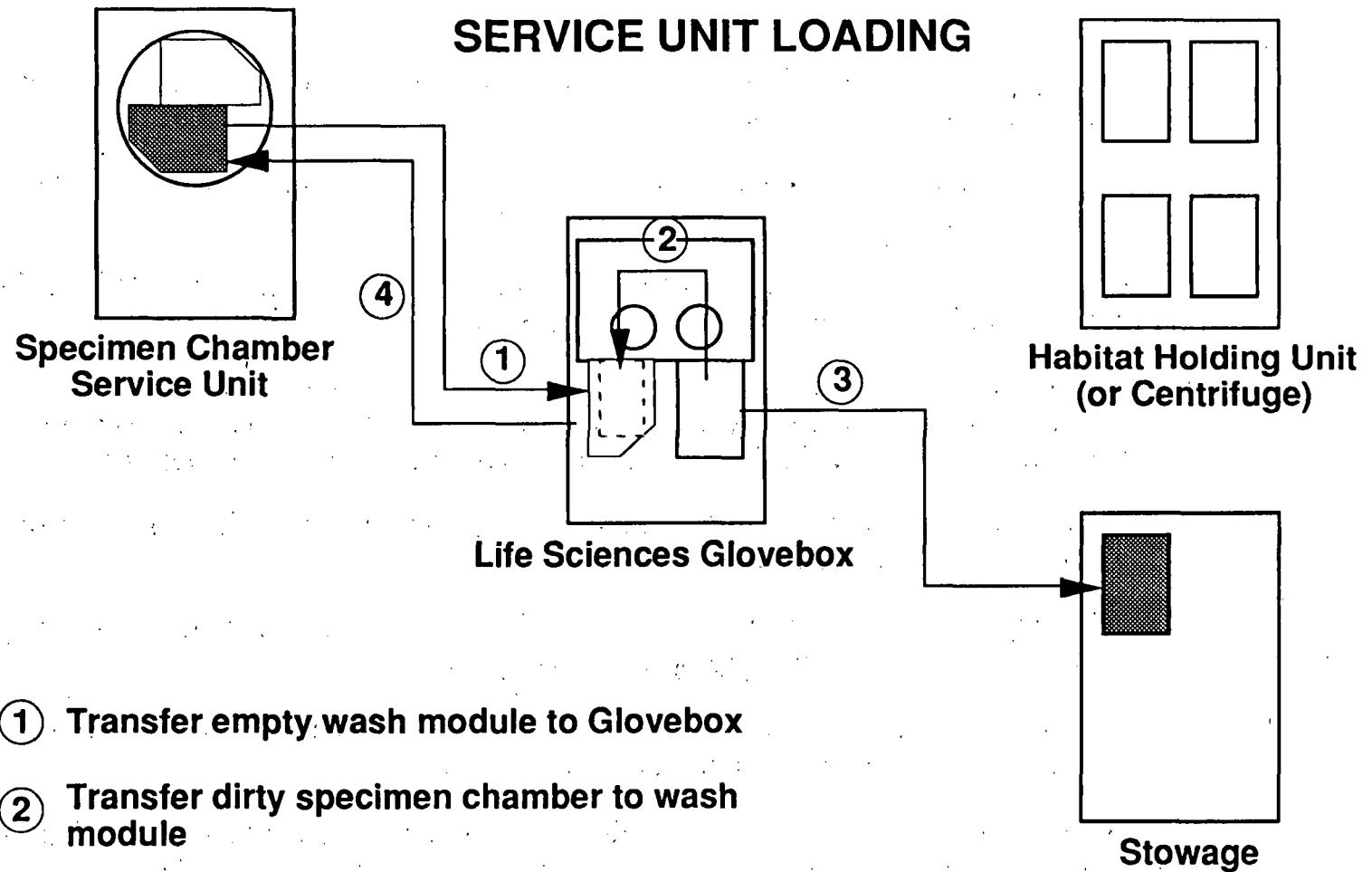
SERVICING SCENARIO (CONT'D)

2) Dirty Specimen Chamber Transfer:

- i) Open protective doors of the Service Unit: retrieve one wash module from Service Unit; transport it to the Glovebox;
- ii) Slide wash module into unoccupied habitat slot on the Glovebox; open door to wash module;
- iii) Open outer and inner doors of the dirty habitat; vacuum interior of soiled specimen chamber while chamber is still contained inside habitat;
- iv) Disconnect sensors, lixits, and food dispensers from specimen chamber; remove specimen chamber/waste tray assembly; detach waste tray; remove waste tray liner from waste tray; discard liner into trash container located in a gloveport;
- v) Place specimen chamber and then the waste tray into wash module basket and fix using TBD attachment method (clips);
- vi) Wipe exposed surfaces of dirty habitat; replace door to dirty habitat; detach empty habitat and return it to the appropriate stowage area;
- vii) Close door to wash module; detach wash module and transport it to the Service Unit; slide it into the appropriate slot on the rotating mount;

Repeat steps 1.i-1.vi and 2.i-2.vii for another soiled squirrel monkey specimen chamber. After transfer operations are completed, decontaminate and deactivate the Glovebox.

SERVICING SCENARIO (CONT'D)



SERVICING SCENARIO (CONT'D)

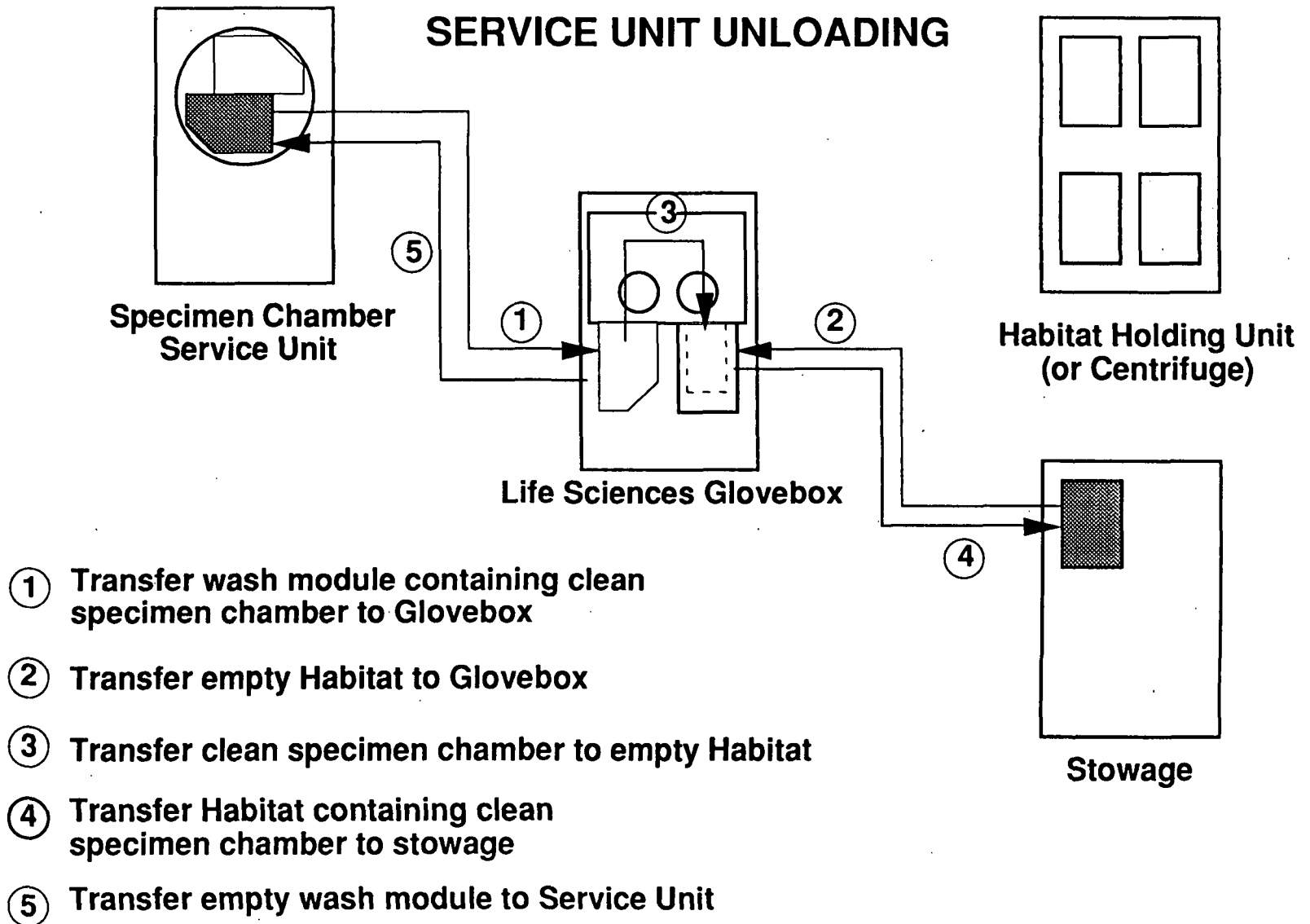
3) Wash:

- i) Close protective doors covering the rotating mount; slide out Service Unit control panel; activate Service Unit; check indicator lights for any malfunctioning subsystems;
- ii) Activate Service Unit computer; instruct it to display procedure and checklist for chamber servicing;
- iii) Program Service Unit for type, duration of wash; start wash cycles;
- iv) Return to Service Unit when TBD indicators signal washing is completed;
- v) Deactivate Service Unit.

4) Clean Specimen Chamber Transfer:

- i) Bring clean waste tray liners and other disposable components of the specimen chamber to the Glovebox (they may be held in a container that attaches to one of the 10 inch gloveports or an equipment module that fits in one of the Habitat slots);
- ii) Open protective doors covering the rotating mount on the Service Unit; disconnect and transport one wash module to the Glovebox; attach to one open slot on the Glovebox;
- iii) Transport one empty unrestrained squirrel monkey habitat to the Glovebox; attach habitat to the remaining open slot;

SERVICING SCENARIO (CONT'D)



SERVICING SCENARIO (CONT'D)

- iv) Assuming Glovebox is activated and decontaminated, open doors to the wash module and habitat;
- v) Remove clean waste tray liner from storage bag; remove waste tray from wash module; visually inspect waste tray to verify cleanliness; if it appears clean, insert liner into waste tray;
- vi) Remove specimen chamber from wash module; visually inspect specimen chamber to verify cleanliness; if it appears visibly clean, attach it to the waste tray; if either the specimen chamber or waste tray are visibly dirty, place both back into the wash module;
- vii) Place assembly inside habitat; close specimen chamber door; wipe exposed surfaces of habitat; close habitat door;
- viii) Disconnect habitat and transport it to the Holding Facility;
- ix) Remove large particulate filter inside wash module and dispose; close wash module door;
- x) Disconnect wash module and transport it to the Service Unit;

Repeat Steps 4.i-4.x for the other wash module and another empty unrestrained squirrel monkey habitat. Decontaminate and deactivate the Life Sciences Glovebox.

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 9

System Study Summary

SYSTEM STUDY SUMMARY - OUTLINE

The chart on the facing page presents an outline of this chapter of the report.

SYSTEM STUDY SUMMARY - OUTLINE

- Study Conclusions
- Resource Summary
 - Freedom Interfaces
 - Mass
 - Power
 - Heat Rejection Rates
 - Data Rates
- Design Challenges
- Concerns
- Technology Development
- Continued Efforts

STUDY CONCLUSIONS

This study indicates that a Centrifuge facility, based on systems which use standard Freedom racks, can be developed to satisfy most science requirements; however, the design concept does not have an automatic habitat extractor nor the ability to accommodate Unrestrained Squirrel monkey Habitats on the Centrifuge.

The use of the larger (80") Freedom racks would ease packaging problems, provide design flexibility, and improve accessibility for maintenance. A node mounted centrifuge would allow a larger centrifuge rotor diameter. This would permit the accommodation of the automatic habitat extractor and the Unrestrained Squirrel Monkey Habitats.

Some areas were identified which presented design problems and require further analysis. Examples of this are the control of plant operating parameters at low air flow rates. Requirements now state that Plant Habitat temperatures and humidities must be controlled while flow rates are varied from some upper limit to zero. Controllability will be lost at some point as the flow approaches zero; this limit must be established. The effects of system flow distribution at low flow rates and operations analyses for the Glovebox and the Service Unit are other areas which require further study.

STUDY CONCLUSIONS

- System can be developed which satisfies most science requirements based on use of 74.5" racks
- No unresolvable issues encountered
 - No automatic habitat extractor in small racks
- Larger racks (80") beneficial
 - Provide packaging and design flexibility
- Node mounted centrifuge
 - Permits larger centrifuge
 - Provide packaging and design flexibility
 - Incorporate automatic habitat extractor
- More extensive analyses required
 - Plant Habitat performance (temperature and humidity control at low air flows)
 - System behavior at low air flow rate
 - Operations analysis for Glovebox and Service Unit

FREEDOM INTERFACES

The facing page lists the Freedom interfaces required by the Facility.

Each Facility rack requires the Freedom interfaces listed except the Water Reclamation System (WRS) and gases (Nitrogen, Oxygen, Carbon Dioxide). The WRS interface is required only for those systems which dehumidify the inlet air from the cabin and produce clean condensate. The gases are required only for supporting the Plant Habitats.

The maximum projected data rates at the rack level are about 1/2 the Freedom capability of 10 mbs. Each rack uses the 4°C (40°F) liquid coolant loop, avionics air, and cabin air systems for heat rejection. Most heat from the habitats is removed via forced convection using cabin air. The PMMS system is required to process liquid and solid waste from the Facility.

FREEDOM INTERFACES

- Freedom provided interfaces required for each rack
 - Power (120 Vdc)
 - Data (< 10 mbps thru NIU to local area net)
 - Video
 - Liquid coolant loop (40° F low temperature loop)
 - Avionics air
 - Cabin air
 - Fire suppression (CO₂)
 - Process Materials Management System (solid wastes; dirty condensate)
 - Water Reclamation Management System (for clean condensate)
 - Ultrapure H₂O
 - Nitrogen gas - direct line or recharge tanks
 - Oxygen gas - recharge tanks
 - Carbon dioxide gas - recharge tanks

FACILITY MASS ESTIMATES

The estimated mass of the habitats range from 40 to 75 kg (88 - 160 lbs). Thus, special GSE will be required for ground handling of the habitats and special care will be required during handling while on-orbit. The Facility systems which occupy standard Freedom racks have masses between 450 and 650 kg (1000-1400 lbs); the Centrifuge weighs about twice as much since it occupies 2 standard racks. The total mass of the Facility which is assumed to consist of 2 Holding Systems, 1 each of the remaining systems, and 22 Rodent Habitats is estimated to be about 4300kgs (9600 lbs).

FACILITY MASS ESTIMATES

<u>Item</u>	<u>Mass kg (lbs)</u>
Rodent Habitat	40 (88)
Primate Habitat (unrestrained/restrained)	73/61 (160/135)
Plant Habitat	54 (120)
Holding System w/o habitat	650 (1425)
Centrifuge System w/o habitats	1275 (2809)
Glovebox System w/o habitat & LSE	450 (995)
Service Unit w/o specimen chambers	455 (1005)
Total Facility with rodent Habitats	4360 (9595)
(Includes 2 Holding Systems, 1 each of remaining systems and 22 Rodent Habitats)	

FACILITY POWER ESTIMATES

The facing page shows the average and peak power estimates for each of the habitats and Facility systems. The information should be self explanatory. The total facility power demand depends on the power profile (which can be tailored to reduce power demands) and cannot be obtained by adding the columns. It is estimated that the total Facility (2 Holding Systems and the stated habitat complement) will require between 6-7.5 kW average power and 8-10 kW peak power.

FACILITY POWER ESTIMATES

<u>Item</u>	<u>Ave Power - W</u>	<u>Peak Power - W</u>
Rodent Habitat	43	73
Unrestrained Squirrel Monkey Habitat	55	160
Restrained Squirrel Monkey Habitat	45	155
Plant Habitat	185	306
Holding System		
(without/with) 4 plant habitats	1170/1910	1170/2394
Centrifuge System		
(without/with) 4 plant & 2 Rodent Habitats	1805/2838	2265/3978
Glovebox System		
(without/with) habitats and LSE	1320/1890	1435/2245
Service Unit	750	1250

FACILITY THERMAL CHARACTERISTICS

The facing page shows the estimated heat loads for each Facility System for the indicated habitat complements. Most of the heat is rejected via the Freedom liquid coolant loop, some heat is rejected to the Freedom cabin air (primarily from the modular habitats), and the balance of the heat is rejected to the avionics air system. The Freedom low temperature 4°C (40° F) coolant loop is required to achieve the desired temperatures in the habitats, and for condensing vapors. Due to the difficulty of ducting avionics air to the habitats, most habitat heat rejection is via forced convection to the cabin air.

FACILITY THERMAL CHARACTERISTICS

Average Heat Rejection Rates - W

<u>Item</u>	<u>Holding</u> <u>System</u>	<u>Centrifuge</u> <u>System</u>	<u>Glovebox</u> <u>System</u>	<u>Service</u> <u>Unit</u>
Habitat complement (maximum thermal loads)	4 Plant	4 Plant & 2 Rodent	2 Plant & LSE (microscope)	N/A
Heat rejected to 40° F coolant	1260	2024	1425	650
Heat rejected to cabin air	363	534	315	50
Heat rejected to avionics air	286	280	150	50

FACILITY DATA CHARACTERISTICS

The facing page summarizes the data requirements for each of the Facility systems. The highest nominal data rate for any system is about 2 mbps with a peak of 5.4 mbps. Internal video channels are multiplexed to obtain 1 output at the rack interface. The Glovebox requires more video outputs and a video input in order to facilitate telescience between the flight crew and ground operators during glovebox experimental operations.

FACILITY DATA CHARACTERISTICS

<u>Item</u>	<u>Holding</u> <u>System</u>	<u>Centrifuge</u> <u>System</u>	<u>Glovebox</u> <u>System</u>	<u>Service</u> <u>Unit</u>
Science data				
- nominal (Kbps)	< 2000	< 1500	< 700	0
- max (Kbps)	< 5400	< 4070	< 2200	0
Eng. data (Kbps)	< 6.2	< 81	< 5.8	< 12.4
Total data rate				
- nominal (Kbps)	< 2006	< 1581	< 706	< 12.4
- max (Kbps)	< 5430	< 4150	< 2206	< 1000
Internal video	≤16 Channels	≤ 12 Channels	≤ 7 Channels	None
Video output	1 Channel	1 Channel (+ 1 Channel input)	3 Channels	None

DESIGN CHALLENGES

The facing page lists design challenges encountered during the System Concept Study. Perhaps the most difficult challenge was packaging all hardware items within the rack volume. This resulted in a high packing density which could inhibit servicing and prevented the accommodation of the Unrestrained Squirrel Monkey Habitat and an automatic habitat extractor on the Centrifuge.

Maintaining the required number of levels of bioisolation during normal operation presented some difficulty. During some servicing operations, only one level of bioisolation could be maintained, without complicating the systems, until contaminated items could be removed and bagged.

Servicing the habitats at the Holding Systems was limited; most operations, including animal waste sampling, had to be performed in the Glovebox. The design of the Glovebox work volume required many tradeoffs and will result in many operational design challenges.

The Centrifuge hub is a complex subsystem with rotary connections for power, data, video, RF, liquid, and gases. This presented difficult design and packaging challenges.

Some science requirements presented severe design challenges. An example of this is the temperature and humidity control requirement for Plant Habitats as air flow rates are reduced. Control can only be achieved to some lower limit, below which control is impossible.

DESIGN CHALLENGES

- Maintaining 2 levels of bioisolation for all Facility operations at all times
- Packaging hardware within tight volume constraints
- Servicing tightly packaged hardware
- Servicing habitats at the Holding System and Centrifuge
- Sampling animal wastes outside the Glovebox
- Optimizing crew use through design choices
- Accommodating Glovebox operations and support equipment in limited work volume
- Meeting Plant Habitat science requirements such as temperature and humidity control at low flows
- Centrifuge hub with rotary joints
- Automatic habitat and equipment extractor on Centrifuge

CONCERNS

The facing page lists major concerns which were identified in the System Concept Study. Some of the animal housing requirements are still to be verified for the system specifications.

Many system tradeoffs affect one or more science requirements simultaneously. Prioritizing the Science Requirements would provide a basis from which tradeoff decisions could be made.

As mentioned earlier, packaging presented a design challenge and the resultant volume margins are low for Facility systems which utilize the Freedom 74.5" racks. System growth could result in a reduction in the number of habitats accommodated. The 80" racks would help alleviate this problem.

Further definition of bioisolation requirements is required. There may be minor fluid (or gas) loss while connecting or disconnecting the QDs and a small contaminated surface will be exposed. Limits on these parameters need to be defined.

CONCERNS

- Definition/confirmation of specimen housing requirements
 - Major effect on system design
 - Resolution required
- No current prioritization of science requirements
 - Establish interdependence of science requirements
 - Provide a basis for tradeoff decisions
- Volume margins low for 74.5" racks
 - System growth during hardware development could reduce science capability
 - Larger racks would help alleviate problem
- Detailed definition of bioisolation requirements
 - Define allowable fluid loss and contaminated surface exposure for quick disconnects

TECHNOLOGY DEVELOPMENT

The following pages list the key areas in which technology developments are required. The Facility requires many quick disconnects of assorted sizes, all of which should be miniaturized to reduce packaging constraints. The habitats require small fluid connectors, whereas larger sizes are required for connecting replaceable filters in the main ducting. The quick disconnects must satisfy bioisolation requirements, have a long service life, and withstand corrosive environments. Some development will be required.

Highly reliable animal feeders and liquid separators are required. Centrifugal separators were baselined for most of the systems in this study. More reliable separators need to be developed with special emphasis on compact systems for use in the Plant Habitats.

TECHNOLOGY DEVELOPMENT

- Quick disconnects
 - Many required for Facility
 - Maintain bioisolation while connecting and disconnecting. Define allowable fluid loss and contaminated surface exposures
 - Capability for many connections and disconnections over life of Facility
 - Withstand some corrosive environments
- Animal Feeders
 - Require highly reliable systems which are easily maintained
- Liquid separators for dehumidification
 - Centrifugal separators baselined for this study
 - Other options need to be investigated

TECHNOLOGY DEVELOPMENT (CONT)

Some specimens (plants) are very sensitive to vibration. Vibration disturbance limits will be imposed at the Freedom interface with the Facility racks. More extensive analysis is required to determine Facility needs for vibration isolation.

The hubs on the Centrifuge and Service Unit must provide rotary fluid and gas connections and have a long service life since maintenance will be difficult. Some development will be required.

Technology development is required for Plant Habitat lighting systems and oxygen scrubbers (to maintain oxygen levels within limits). Preferred lighting sources are high intensity LED's but further study is required. To ease design and thermal control problems, oxygen scrubbers with little exothermic reaction are required.

TECHNOLOGY DEVELOPMENT (CONT)

- Vibration isolation
 - Vibration isolation may be required for some Facility hardware
 - More extensive analyses are required to assess needs
- Rotary Fluid Connections
 - Fluids cross the Centrifuge and Service Unit hubs
 - Compact and reliable long life joints are required
- Plant illumination sources
 - High illumination levels are required
 - Freedom is expected to constrain user power
 - High output LED's and blue light LED's require further development
- Oxygen Scrubbers
 - Plant experiments require a wide atmospheric composition range
 - Must develop efficient methods for controlling oxygen

CONTINUED EFFORTS

Future efforts will focus on areas not covered in this report, such as Freedom node mounted centrifuges. Furthermore, analyses and some experimental efforts will be performed in the areas indicated under related studies.

CONTINUED EFFORTS

- Continued System Studies
 - Examine Spacelab applications and Freedom node mounted Centrifuges
 - Examine areas identified in study which require further work
 - Dynamics analysis for Centrifuge and Service Unit
 - Operations analysis for Glovebox and Service Unit
 - Plant Habitat Components: lights, oxygen scrubbers, humidity control systems
 - Perform limited experimental studies
 - Air flow tests at low flow rates
 - Human factors test of Glovebox work volume on KC-135 flights
 - Continue studies related to the "clean" versus "replace" tradeoff for specimen chamber servicing
- Work on related studies
 - Plant vibration studies
 - Animal habitat studies

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16. Abstract The Centrifuge Facility Conceptual System Study presents results of a NASA phase—A study conducted from mid 1987 through mid 1989 at Ames Research Center. The Centrifuge Facility is the major element of the biological research facility for the implementation of NASA's Life Science Research Program on Space Station Freedom using non-human specimens (such as small primates, rodents, plants, insects, cell tissues). This report describes five systems which comprise the Facility. 1) Habitats – modular units which house living specimens; 2) Holding Unit – system which supports and supplies resources for habitats in micro-gravity; 3) Centrifuge – system which supports and supplies resources to habitats on a rotating structure to simulate gravitational acceleration; 4) Glovebox – system which provides a closed, controlled environment for experimental procedures on specimens and habitat servicing; 5) Service Unit – system which replaces or cleans specimen chambers. This report is issued in three volumes. Volume I describes Habitats; Volume II describes the Holding Unit, Centrifuge, Glovebox, and Service Unit; and Volume III describes a concept for a larger centrifuge.					
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